MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 98 No. 4

1938 FEBRUARY 11

ANNUAL GENERAL MEETING

Dr. H. Spencer Jones, President, in the Chair.

The Minutes of the preceding Annual General Meeting were read and confirmed.

The election by the Council of the following Fellow was duly confirmed :—

Joseph Bernard Ayscough-Clarke, M.C.I., M.I.St.E., M.I.E.E., 54 Beaufort Mansions, Beaufort Street, London, S.W. 3.

The following candidates were proposed for election as Fellows of the Society, the name of the proposer from personal knowledge being appended :—

Ronald George Foster, M.Sc., 261 Kent House Road, Beckenham, Kent (proposed by W. J. Langford) ;

Rev. H. Hancock, M.A., F.R.S.A., F.R.Met.Soc., 88 Heene Road, Worthing (proposed by R. C. Morrell) ;

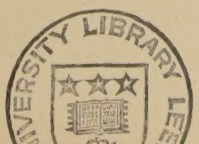
John Robert Fisher Jeffreys, Downing College, Cambridge (proposed by R. v. d. R. Woolley) ;

Charles William Bloomfield Michie, Box 107, Kaitaia, New Zealand (proposed by F. J. M. Stratton) ;

Thomas Silcock, B.A., Heap Lynn, Seaton Lane, West Hartlepool, Co. Durham (proposed by J. A. Holden) ;

Wen-Sai Tai, Gonville and Caius College, Cambridge (proposed by F. J. M. Stratton) ; and

Ivan Leslie Thomsen, Dominion Observatory, Wellington, New Zealand (proposed by F. J. M. Stratton).



The Address on the award of the Gold Medal was delivered by the President (see p. 358), after which the Gold Medal was handed to the First Secretary of the American Embassy, Mr. Millard, for transmission to Dr. W. H. Wright, Director of the Lick Observatory, to whom it had been awarded for his studies of the spectra of gaseous nebulæ and of novæ and for his work on the photography of planets in light of different colours.

The President then delivered short Addresses on the awards of the Jackson-Gwilt Medals and Gifts (see p. 375), after which a Jackson-Gwilt Medal and Gift were handed to Mr. F. J. Hargreaves (to whom the Medal had been awarded for his contributions to astronomy) and to the Secretary for transmission to Mr. P. M. Ryves (to whom the Medal had been awarded for his observations of variable stars and other astronomical work).

Visitors were then requested to withdraw and the Society proceeded to the formal business of the Meeting.

The Report of the Auditors was read (see p. 237) and the Treasurer made a short statement on the financial position of the Society.

A vote of thanks to the Auditors of the Treasurer's Accounts was proposed and carried unanimously.

The Annual Report of the Council was partly read.

The following motion was proposed by the Secretaries and carried unanimously :—

"That the following addition be made to bye-law 22 :—

"In the event of a former Fellow seeking re-election, the Council may, if it thinks fit, waive the Admission Fee normally payable on re-election, it being understood that in all such cases the individual concerned must be formally proposed and submitted for election as provided in bye-laws 13 to 20, apart from the payment of the Admission Fee."

[*Bye-law* 22. The contribution of each Fellow hereafter elected shall, for the first year, be four guineas or three guineas, according to the month in which he may have been elected (viz. two guineas in all cases as an admission-fee, and two guineas as the first year's contribution, if such election has taken place in the month of January, February, March, April, May or June ; but only one guinea as the first year's contribution, if such election has taken place in the month of October, November, or December), payable at the time of his election ; and two guineas for every subsequent year ; the first of such subsequent contributions to become due and be payable in advance on the 1st day of January in every subsequent year.]

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Auditors and the President's Addresses.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 378.

Dr. Steavenson showed some of the slides recently added to the Society's collection, and also two portraits of Mr. Richard Inwards and Mrs. Jackson-Gwilt.

The thanks of the Society were given to the retiring members of Council.

The thanks of the Society were also given to the Scrutineers of the ballot.

The Meeting then adjourned.

REPORT OF THE COUNCIL TO THE HUNDRED AND EIGHTEENTH ANNUAL GENERAL MEETING OF THE SOCIETY.

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Honorary Member	Fellows		Associates	Total
				Compounders	Annual Subscribers		
1936 December 31	1	4	1	210	661	46	923
Since elected	...	...	...	...	+35	+2	...
Restored to list	...	...	...	...	+ 2	...	...
Deceased, 1937	...	...	...	− 7	−14	...	...
Deceased before 1937, not reported	...	...	...	− 2	− 1	...	...
Resigned	...	...	...	...	−15	...	...
Since compounded	...	...	...	...	...	...	...
Removed from list	...	...	...	...	− 6	...	...
1937 December 31	1	4	1	201	662	48	917

(Eight Associates are also Fellows, and are therefore counted twice in the above table.)

RECEIVED

	£ s. d.	£ s. d.
Balances, 1937 January 1:—		
In hand of Assistant Secretary on Petty Cash Account	6 18 5	
At Bankers', on Current Account (including Spencer Bequest, £21, 16*s.* 2*d.*) ...	611 1 5	
At Bankers', on Deposit:—		
Balance of Spencer Bequest £411 0 0		
Advance payments for Franklin-Adams Charts 423 0 0		
	834 0 0	
At Bankers', on "C" Account:—		
Trust Funds 180 12 8		
Proceeds of Sales of Duplicate Books 54 0 6		
	234 13 2	
		1686 13 0
Received on account of Dividends:—		
£1250 Metropolitan Consolidated 3% Stock	37 10 0	
£2000 Swansea Corporation 3½% Stock	70 0 0	
£2287, 6*s.* 9*d.* East Indian Railway 3% Debenture Stock	51 13 4	
£5125 London, Midland and Scottish Railway 4% Debenture Stock...	155 0 7	
£750 London, Midland and Scottish Railway 4% Preference Stock	22 13 9	
£2400 Gas Light and Coke Co. 3% Consolidated Debenture Stock	54 9 0	
£2000 Commercial Gas Co. 3% Debenture Stock	45 0 0	
£1035 Agricultural Mortgage Corporation 4% Debenture Stock, 1961–91	34 18 8	
£695, 16*s.* Conversion Loan 3½% Stock, 1961	24 7 0	
£419, 17*s.* 11*d.* Conversion Loan 4½% Stock, 1940–44	18 17 10	
£700 Birmingham Corporation 3% Inscribed Stock, 1947	21 0 0	
£496 Consolidated Loan 4%	19 16 8	
£2000 New Zealand Consolidated 3½% Loan, 1940	70 0 0	
£1000 Hull Corporation 4½% Redeemable Stock, 1952–72	45 0 0	
£800 War Loan 3½% Inscribed Stock	28 0 0	
£300 New South Wales 4% Stock, 1942–62	15 2 6	
£1000 Central Electricity Board 4½% Stock, 1947–82	34 0 8	
Income Tax refunded, 1936 April–1937 April	129 19 2	
Interest on Deposit Account	3 14 10	
	881 4 0	
Sales of Publications £361 2 4		
Reprints 87 16 10		
	448 19 2	
Sales of Photographs	58 16 0	
Sales of Duplicate Book from Library...	4 10 0	
Miscellaneous Receipts:—		
Graticules for Franklin-Adams Charts (1st and 2nd editions) 24 10 0		
London Mathematical Society, Expenses of Meetings 31 10 0		
Assistant Secretary and Clerk, Pension Premiums 19 5 0		
Postages, etc., repaid 4 5 3		
Use of Telephone 0 6 0		
Excess on Subscriptions 0 3 11		
	80 0 2	
		1473 9 4
Franklin-Adams Charts, Sections 1 and 2	612 0 0	
Advance payments for Section 3	54 0 0	
	666 0 0	
Less refunds in respect of Subscribers deceased	36 0 0	
		630 0 0
Dividends on £700 War Loan 3½% Inscribed Stock (Spencer Bequest) *	... ...	21 0 0
Received on account of Subscriptions:—		
578 Annual Contributions for 1937 (including 2 Institutional Membership Fees) ...	1213 16 0	
23 Annual Contributions for 1938 in advance (including 1 Institutional Membership Fee)	48 6 0	
35 Admission Fees	73 10 0	
4 First Contributions at 1 guinea	4 4 0	
31 First Contributions at 2 guineas	65 2 0	
Arrears paid off:—		
2 for 1934 ... ... £4 4 0		
10 for 1935 ... ... 21 0 0		
49½ for 1936 ... ... 103 19 0		
	129 3 0	
		1534 1 0
Trust Funds:—		
Dividends:—		
£1212, 13*s.* 3*d.* East Indian Railway 3% Debenture Stock	27 8 3	
£542, 18*s.* 2*d.* India 3½% Stock	19 0 0	
£965 Agricultural Mortgage Corporation 4½% Debenture Stock, 1961–91 ...	32 11 6	
£1004 Consolidated Loan 4%	40 3 2	
Donation from General Fund (balance of George Darwin Lecture Fee)	9 16 10	
Income Tax refunded, 1936 April–1937 April	18 18 11	
Goodridge Bequest (transferred from General Fund)	50 0 0	
Capps Gift (Stillhamer Bequest)	500 15 0	
		698 13 8
		£6043 17 0

* Added to value of Bequest in Balance Sheet.

Examined and found correct.

(Signed) E. A. CHAMBERLAIN.
W. E. CANDLER.

1938 *January* 17.

ASTRONOMICAL SOCIETY, FROM 1937 JANUARY 1 TO DECEMBER 31

Account

PAID

	£ s. d.	£ s. d.
Assistant Secretary: Salary	270 0 0	
Clerk: Salary	190 0 0	
Assistant Secretary and Clerk, for work done for London Mathematical Society	10 0 0	
Pension Premiums for Assistant Secretary and Clerk	57 15 0	
Porter and Wife: Wages	163 17 0	
Health and Unemployment Insurance	6 11 3	
		698 3 3
Licence for Porter	0 15 0	
Fire and Accident Insurance	16 3 3	
Telephone	13 14 1	
Telegraphic Address	2 0 0	
Water Rate	12 12 0	
		45 4 4
Postage and Packing:—		
Monthly Notices, etc.	129 16 10	
Office Postages	60 13 0	
		190 9 10
Printing, etc.:—		
Monthly Notices (Vol. **97**, Nos. 1–9)	879 16 8	
Geophysical Supplements (Vol. **4**, Nos. 1–3)	266 13 7	
Reprints	133 10 1	
List of Fellows, 1937	40 13 8	
Miscellaneous	38 9 5	
Photo-engraving:—		
Monthly Notices £63 10 6		
Geophysical Supplements 10 17 1		
	74 7 7	
		1433 11 0
Reproduction of Photographs for sale	45 7 8	
Stationery and Office Expenses	32 8 3	
Reproduction of Scarce Numbers of *Monthly Notices* (Replika)	8 12 0	
Hire of Cinematograph	8 9 2	
Reproduction of Graticules for 1st and 2nd editions of Franklin-Adams Charts	32 2 5	
Coronation Decorations, etc.	47 8 1	
Valuation of Society's Property	30 9 4	
Rebinding Old Books (Potter Fund)	10 9 6	
Subscription to International Telegrams Bureau	6 6 3	
Subscription to Committee on Library Co-operation	1 1 0	
Authorised Travelling Expenses	18 5 3	
Heating and Lighting	105 12 6	
Fittings and Repairs (including Office of Works Account, £46, 10s. 7*d*.)	99 19 11	
Library Equipment and Purchase of Books (General Fund)	1 11 1	
Jubilee Address to Professor Fabry	4 10 0	
Balance of George Darwin Lecture Fee	9 16 10	
House Expenses and Laundry	38 17 8	
Expenses of R.A.S. Meetings and Committees	18 11 7	
Expenses of Geophysical Meetings	6 8 10	
Expenses of London Mathematical Society Meetings	7 7 3	
Miscellaneous Expenditure	9 8 6	
Bank Charges and Cheque Books	3 7 3	
		546 10 4
Purchase of Book from Funds raised by sale of Duplicate Books	... ...	16 17 6
		2930 16 3
Expenditure on Franklin-Adams Charts:—		
Sections 1 and 2	699 6 7	
Section 3	85 1 7	
		784 8 2
Expenditure from Spencer Bequest:—		
Binding	5 13 6	
Safes for MSS.	18 14 0	
Grant to Harvard College Observatory, for work done for Royal Observatory, Cape of Good Hope	80 0 0	
		104 7 6
Purchase of £200 War Loan 3½% Inscribed Stock (Spencer Bequest)	... ...	200 18 6
Transfer to "C" Account (Goodridge Bequest)	... ...	50 0 0
Expenditure on Trust Accounts:—		
George Darwin Lecture Fee	50 0 0	
Turnor and Horrocks Fund (Library)	15 9 11	
Harry Watson Fund (Library)	87 2 5	
Purchase of £540, 10s. 4*d*. War Loan 3½% Inscribed Stock (Stillhamer and Goodridge Bequests)	550 15 0	
		703 7 4
Balances, 1937 December 31:—		
In hand of Assistant Secretary on Petty Cash Account	0 11 5	
At Bankers', on Current Account	804 5 8	
At Bankers', on Deposit:—		
Cash Balance of Spencer Bequest £148 10 2		
Advance Payments for Franklin-Adams Charts, Section 3 99 0 0		
	247 10 2	
At Bankers', on "C" Account:—		
Trust Funds 175 19 0		
Proceeds of Sale of Duplicate Books 41 13 0		
	217 12 0	
		1269 19 3
		£6043 17 0

Revenue

	£	s.	d.	£	s.	d.
To General Expenditure as per Cash Account	2930	16	3			
,, Reserve for Accounts due but not presented...	285	0	0			
	3215	16	3			
Less Reserve for Accounts due 1936 now written back ...	195	0	0			
				3020	16	3
,, Annual Reserve for Repairs and Maintenance				40	0	0
,, 12 Annual Contributions in Arrear written off	25	4	0			
,, 9 Annual Contributions 1937 written off as per contra ...	18	18	0			
				44	2	0
				£3104	18	3

Examined and found correct.

(Signed) E. A. CHAMBERLAIN.
W. E. CANDLER.

1938 *January* 17.

Account, 1937

		£ s. d.	£ s. d.
By Subscriptions—			
578	Annual Contributions 1937, including 2 Institutional Membership Fees	1213 16 0	
19	ditto, 1937 (including 1 Institutional Membership Fee), paid 1936 and now matured	39 18 0	
58	ditto, outstanding (including 1 Institutional Membership Fee)	121 16 0	
9	Contributions for 1937 due, but unpaid, in respect of Fellows resigned, or names removed, and written off per contra	18 18 0	
664			1394 8 0
,, 1	Subscription 1934–36 written off in 1936 and now recovered...		6 6 0
,, 31	First Contributions at 2 guineas	65 2 0	
4	ditto at 1 guinea	4 4 0	
35			69 6 0
35	Admission Fees at 2 guineas		73 10 0
,,	6% of Composition Fees Reserve Fund as per Balance Sheet, transferred to Current Revenue		39 3 9
,,	Sundry Debtors for Publications and Photographs, 1937 ...		17 4 10
,,	Dividends, Sales of Publications and Photographs, and Miscellaneous Receipts, as per Cash Account	1473 9 4	
Less	Payments due 1936 ... ... £15 10 4		
	Advance payments for *Monthly Notices*, Vol. 98 ... ... 49 9 9		
	Income Tax (General Fund) 1936 April–December, refunded in 1937 ... 81 14 2		
		146 14 3	
			1326 15 1
,,	Payments for *Monthly Notices*, Vol. 97, received in 1936 and now matured		48 7 3
,,	Income Tax (General Fund) deducted at source 1937 April–December, not yet refunded		86 0 4
,,	Excess of Expenditure and Reserve over Income, 1937 ...		43 17 0
			£3104 18 3

Balance Sheet

LIABILITIES

	£ s. d.	£ s. d.
23 Subscriptions for 1938, paid in 1937		48 6 0
Sundry Creditors for Accounts due but not presented ...		285 0 0
Annual Reserve for Repairs and Maintenance...		40 0 0
Cash Balances (Income) of Trust Funds—		
Turnor and Horrocks Fund	8 10 9	
Harry Watson Fund	30 10 0	
Lee and Janson Fund	66 13 6	
Jackson-Gwilt Fund	50 3 2	
George Darwin Lectureship Fund	20 1 7	
		175 19 0
Trust Funds (Capital), as per contra		3514 15 0
Income Tax on Trust Funds, 1937 April–December, not yet refunded		17 13 3
Special Fund (Capital), as per contra		1460 0 0
Composition Fees Reserve Fund—		
As at 1936 December 31	653 4 6	
Less 6% transferred to current revenue	39 3 9	
		614 0 9
Franklin-Adams Charts—		
Balance of liability from 1936	210 12 0	
Received in 1937 (£666 *less* £36 refunded)	630 0 0	
Due for Sections 1 and 2	45 0 0	
	885 12 0	
Less expenditure on charts, 1937	784 8 2	
		101 3 10
Advance payments for *Monthly Notices*, Vol. 98		49 9 9
Credit for overpayment on publications, 1932		0 11 0
General Fund—		
As at 1936 December 31	18,661 0 10	
Add Dividends, Spencer Bequest	21 0 0	
	18,682 0 10	
Deduct Cash Expenditure from Bequest, 1937	104 7 6	
	18,577 13 4	
Deduct Goodridge Bequest, transferred to Trust Funds	50 0 0	
	18,527 13 4	
Add Lindley Bequest	1156 1 5	
	19,683 14 9	
Deduct Excess of Expenditure and Reserve over Income, 1937	43 17 0	
		19,639 17 9
		£25,946 16 4

Examined and found correct.

(Signed) E. A. CHAMBERLAIN.
W. E. CANDLER.

1938 *January* 17.

1937 *December* 31

ASSETS

	£ s. d.	£ s. d.
Sundry Debtors for Subscriptions in Arrears—		
1 for 1935 (*less* 11*s.*)	1 11 0	
15 for 1936 (*less* 16*s.*)	30 14 0	
58 for 1937	121 16 0	
		154 1 0
Sundry Debtors for Publications and Photographs		17 4 10
Due for Franklin-Adams Charts, Sections 1 and 2		45 0 0
Investments of General Fund, valued as in 1936 Balance Sheet	17,493 9 6	
Add Lindley Bequest...	1156 1 5	
		18,649 10 11
Investment of £500 Spencer Bequest, 1936	531 13 3	
Investment of £200 Spencer Bequest, 1937	200 18 6	
		732 11 9
Investments of Special Fund, valued at cost		1460 0 0
Investments of Trust Funds, valued as in 1936 Balance Sheet...	2964 0 0	
Add Investment of Capps Gift (Stillhamer Bequest) and Goodridge Bequest, valued at cost...	550 15 0	
		3514 15 0
Income Tax 1937 April–December, deducted at source and not yet refunded—		
General Fund	86 0 4	
Trust Funds	17 13 3	
		103 13 7
Sundry Balances—		
In hand of Assistant Secretary on Petty Cash Account ...	0 11 5	
At Bankers', on Current Account	804 5 8	
At Bankers', on Deposit—		
Cash Balance of Spencer Bequest ... 148 10 2		
Advance payments for Franklin-Adams Charts, Section 3 ... ... 99 0 0		
	247 10 2	
At Bankers', on " C " Account—		
Trust Funds 175 19 0		
Proceeds of Sales of Duplicate Books ... 41 13 0		
	217 12 0	
		1269 19 3
		£25,946 16 4

Astronomical and other Manuscripts, Books, Prints, Photographs and Instruments.	Value not specified.
Furniture, etc.	
Stock of Publications and Photographs for sale.	
One Gold Medal.	
Three Bronze (Jackson-Gwilt) Medals.	

INVESTMENTS

As at 1937 December 31

General Fund

£1250 Metropolitan Consolidated 3-per-cent. Stock, 1941.
£2000 Swansea Corporation 3½-per-cent. Stock.
£2287, 6*s.* 9*d.* East Indian Railway 3-per-cent. New Debenture Stock.*
£5125 London, Midland and Scottish Railway 4-per-cent. Debenture Stock.*
£750 London, Midland and Scottish Railway 4-per-cent. Preference Stock.*
£2400 Gas Light and Coke Co. 3-per-cent. Consolidated Debenture Stock.*
£2000 Commercial Gas Co. 3-per-cent. Debenture Stock.*
£496 Consolidated 4-per-cent. Loan, 1967.
£500 Agricultural Mortgage Corporation, Ltd., 4½-per-cent. Debenture Stock, 1961–91.*
£1000 Hull Corporation 4½-per-cent. Redeemable Stock, 1952–72.
£1000 Central Electricity Board 4½-per-cent. Stock, 1957–82.*
£2000 New Zealand 3½-per-cent. Loan, 1940.
£700 Birmingham Corporation 3-per-cent. Inscribed Stock, 1947.
£1500 War Loan 3½-per-cent. Inscribed Stock.
£500 New South Wales 4-per-cent. Stock, 1942–62.*
£1156, 1*s.* 5*d.* Metropolitan Water Board 3-per-cent. "B" Stock.*

Grove-Hills Special Fund

£419, 17*s.* 11*d.* Conversion Loan 4½-per-cent., 1940–44.
£695, 16*s.* 0*d.* Conversion Loan 3½-per-cent., 1961.
£535 Agricultural Mortgage Corporation, Ltd., 4½-per-cent. Debenture Stock, 1961–91.*

Trust Funds

£1212, 13*s.* 3*d.* East Indian Railway 3-per-cent. New Debenture Stock.*
£542, 18*s.* 2*d.* India 3½-per-cent. Stock.
£1004 Consolidated 4-per-cent. Loan, 1967.
£965 Agricultural Mortgage Corporation, Ltd., 4½-per-cent. Debenture Stock, 1961–91.*
£540, 10*s.* 4*d.* War Loan 3½-per-cent. Inscribed Stock.

* Taxed at source.

REPORT OF THE AUDITORS FOR THE YEAR 1937

We have examined the Treasurer's account of receipts and expenditure, the Revenue Account and the Balance Sheet for the year 1937, and have certified them to be correct. All the investment holdings have been certified by the Bank of England or by the Westminster Bank.

The excess of £43, 17*s.* of expenditure over income does not compare unfavourably with past years. A sum of £40 has been put aside for repairs and maintenance; this item will in future be an annual charge. Extraordinary expenditure has been incurred on Coronation decorations and on the revaluation of the Society's property. The property has been reinsured, the net increase in policy being £4000.

The insurance policies together with a copy of the inventory provided by the revaluation are now kept at the Westminster Bank.

During the year the Goodridge Bequest and the Capps Gift (Stillhamer Bequest) have been invested. The Society's General Funds have been increased by a generous legacy of £1000 from the late Miss Julia Lindley, which has been received from the Public Trustee in the form of £1156, 1*s.* 5*d.* Metropolitan Water Board 3-per-cent. "B" Stock.

No composition fees having been received in 1937, the sum held in reserve in respect of the liability to Fellows who have compounded is £614 as compared with £653 in 1936.

A third edition of the *Franklin-Adams Chart of the Sky* has been published by the Society. Sections 1 and 2 have been distributed to subscribers, and Section 3 will be ready shortly.

No further books have been reported as missing. The most valuable of the historical manuscripts in the possession of the Society have been transferred to fireproof safes, the cost of which has been met by the Spencer Bequest.

We have inspected the Society's premises. These appear to be generally satisfactory, except that the walls and ceiling of the staircase are in need of redecoration.

A list has been laid on the table containing the names of those Fellows who are still in arrear for sums due on 1937 January 1, with the amount due against each Fellow's name.

We have received from the Assistant Secretary all the information and explanations we have required.

(Signed) E. A. CHAMBERLAIN.
W. E. CANDLER.

1938 *January* 19.

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift: In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were repurchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856): Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876): R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

The Lambert Bequest (1877): C. J. Lambert, Esq., presented to the Society the sum of £500, free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905): Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

The Farrar Bequest (1906): The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

The Parsons Gift (1922): The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929–47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1867 October 31.

The Grove-Hills Bequest (1922): Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

The Lindemann Bequest (1931): A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

The Archdeacon Potter Bequest (1933): Archdeacon Beresford Potter bequeathed to the Society a 3/88th share of his residuary estate, amounting to £318, 16*s.* 2*d.* to date.

The Herbert Spencer Bequest (1936): Mr. Herbert Spencer, who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment.

The Goodridge Bequest (1936): Captain J. J. L. Goodridge bequeathed to the Society the sum of £50, free of legacy duty.

The Lindley Bequest (1937): Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which has been received from the Public Trustee in the form of £1156, 1*s.* 5*d.* Metropolitan Water Board 3-per-cent. "B" Stock.

The A. G. Stillhamer Trust (1937): The late Mr. A. G. Stillhamer, F.R.A.S., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr. Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr. Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific instruction or research.

THE GROVE-HILLS SPECIAL FUND

In 1922 the Treasurer, Col. Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913, 1*s.* 11*d.*, of which £1480, 2*s.* 10*d.* has been invested and is now represented by £535 Agricultural Mortgage 4½ per cent., £419, 17*s.* 11*d.* Conversion Loan 4½ per cent. 1940–44, and £695, 16*s.* Conversion Loan 3½ per cent. 1961.

THE ARCHDEACON POTTER FUND

The late Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a 3/88th share of his residuary estate. The sum of £318, 16*s.* 2*d.* was received in 1933, and now stands invested in £300 3½ per cent. War Stock, the cash balance of £17, 15*s.* 2*d.* being expended on the library in 1934. The Council resolved to allocate the dividends from this Fund for the purposes of the library.

	£	*s.*	*d.*		£	*s.*	*d.*
1937 Jan. 1. Balance of Fund	18	2	3	1937. Re-binding of Books	10	9	6
1937. Dividends, War Stock 3½ per cent.	10	10	0	1937 Dec. 31. Balance of Fund	18	2	9
	£28	12	3		£28	12	3

TRUST FUNDS

The Lee and Janson Fund : In 1834 John Lee, Esq., LL.D., gave £100, and in 1876 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £334, 10*s.* 9*d.* East Indian Railway 3-per-cent. Debenture Stock.

	£	*s.*	*d.*		£	*s.*	*d.*
1937 Jan. 1. Balance of Fund	56	14	8	1937 Dec. 31. Balance of Fund	66	13	6
1937. Dividends, East Indian Railway ...	7	11	3				
Income Tax, 1936 April–1937 April, refunded ...	2	7	7				
	£66	13	6		£66	13	6

The Turnor Fund and the Horrocks Memorial Fund : In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £464, 18*s.* East Indian Railway 3-per-cent. Debenture Stock. In 1876 the Society received a sum of £38, 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks : to this the Society added the sum of £55, 15*s.*, and the whole now stands in £103, 6*s.* East Indian Railway 3-per-cent. Debenture Stock. The interest on these funds is to be used in the purchase of books for the library.

	£	s.	d.		£	s.	d.
1937 Jan. 1. Balance of Fund	7	2	10	1937. Purchase of Books ...	15	9	11
1937. Dividends, East Indian Railway ...	12	16	9	1937 Dec. 31. Balance of Fund	8	10	9
Income Tax, 1936 April–1937 April, refunded ...	4	1	1				
	£24	0	8		£24	0	8

The Harry Watson Memorial Fund : In 1920 Mrs. Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. This gift now stands invested in £542, 18*s.* 2*d.* India 3½-per-cent. Stock. In 1923 Mrs. Watson bequeathed a further sum of £958, 17*s.* to the Society, which now stands invested in £965 Agricultural Mortgage 4½-per-cent. Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated *The Harry Watson Memorial Fund*, to be used for the purchase and binding of books.

	£	s.	d.		£	s.	d.
1937 Jan. 1. Balance of Fund	55	14	9	1937. Purchase of Books ...	22	1	5
1937. Dividends, India 3½ per cent.	19	0	0	Binding	65	1	0
Dividends, Agricultural Mortgage 4½ per cent.	32	11	6	1937 Dec. 31. Balance of Fund	30	10	0
Income Tax, 1936 April–1937 April, refunded	10	6	2				
	£117	12	5		£117	12	5

The Hannah Jackson (née Gwilt) Fund : In 1861 Mrs. Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £309, 18*s.* 6*d.* East Indian Railway 3-per-cent. Debenture Stock ; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	s.	d.		£	s.	d.
1937 Jan. 1. Balance of Fund	40	18	10	1937 Dec. 31. Balance of Fund	50	3	2
1937. Dividends, East Indian Railway ...	7	0	3				
Income Tax 1936 April–1937 April, refunded ...	2	4	1				
	£50	3	2		£50	3	2

The George Darwin Lectureship Fund : In 1926 June Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4-per-cent. Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

	£	s.	d.		£	s.	d.
1937 Jan. 1. Balance of Fund	20	1	7	1937 June. Lecture Fee	50	0	0
1937. Dividends, Consolidated 4-per-cent. Loan	40	3	2	1937 Dec. 31. Balance of Fund	20	1	7
Donation from General Fund	9	16	10				
	£70	1	7		£70	1	7

CELESTIAL PHOTOGRAPHS

The following have been added to the list of Celestial Photographs reproduced by the Society for sale to Fellows :—

R.A.S. Serial No.	Ref. No.	
494	A 40.	Solar Corona, 1936 June 19. Chios. R. L. Waterfield. 6-in. O.G., *f.l.* 12½ feet. Exp. 15 s.
495	A 41.	Solar Corona, 1936 June 19. Chios. R. L. Waterfield. 6-in. O.G., *f.l.* 12½ feet. Exp. 1 s.
496	L 37.	Milky Way, Cas., And. R.A. 0 h. 36 m. Dec. +49°. Ross, Yerkes. 5-inch lens. 1930 Oct. 16. Exp. 3 h.
497	L 38.	Milky Way, Cas., Per. R.A. 1 h. 37 m. Dec. +63°. Ross, Yerkes. 5-inch lens. 1934 Sept. 6–7. Exp. 3 h.
498	L 39.	Milky Way, Per., Aur. R.A. 4 h. 42 m. Dec. +32°. Ross, Yerkes. 5-inch lens. 1935 Sept. 21–22. Exp. 4 h.
499	L 40.	Milky Way, Orion. R.A. 5 h. 26 m. Dec. −1°. Ross, Yerkes. 5-inch lens. 1935 Oct. 5–6. Exp. 4 h.
500	J 96.	Nebula I.C.1613 (Cetus). Baade, Mt. Wilson. 100-inch Reflector, *f.l.* 504 inches. 1933 Nov. 14.
501	J 97.	Nebula N.G.C. 3188, '87, '90, '93 (Leo). Mt. Wilson. 100-inch Reflector, *f.l.* 504 inches. 1935 Dec. 24.

PUBLICATIONS OF THE SOCIETY

During the past year the Society has published *Monthly Notices*, vol. 97 ; *Geophysical Supplements*, vol. 4, Nos. 1, 2 and 3 ; *Memoirs*, vol. 65, pt. 4 ; and *Franklin-Adams Chart of the Sky*, 3rd edition, Sections 1 and 2.

OBITUARY

The Council regret that they have to record the loss by death of the following Fellows during the past year :—

John Robinson Airey
Thomas Angus
Charles Edward Barns
Arthur Frederick Bennett
Richard Edward Synge Cooper
Edwin Bailey Elliott
Samuel Fellows
John McDougal Field
Louis Napoleon George Filon
Samuel Forster Grace
*Frederic J. Hall
Maures Horner
Thomas Charlton Hudson
Richard Inwards
Alfred Robert Johnson
†John Cairns Mitchell
Charles Edward Monro
‡Frederick Poate
William Edward Raymond
Bernard P. Scattergood
Ambrose Swasey
Huish Webber
John Williams
James Ernest Grant Yalden

JOHN ROBINSON AIREY was, in the field of mathematics, an amateur in the fullest and best sense of the word, and his career must remain an inspiration to both amateur and professional workers in science alike. Born in Leeds in 1868 his preliminary education was received at the Blenheim Board School and the Leeds Central High School. After joining the staff of the latter he continued his studies at Yorkshire College, and took the degree of B.Sc. as an external student of the University of London in 1894. At the age of thirty-five, with rare and characteristic courage, he abandoned his second mastership at Porth Intermediate School, Glamorganshire, to enter St. John's College, Cambridge. He took his B.A. in 1906, obtained

* Died 1936. Death not reported till 1937.
† Died *circa* 1930. Death not reported till 1937.
‡ Died 1935. Death not reported till 1937.

first-class honours in both Part I and Part II of the Natural Science Tripos, and was awarded the Wright, Hockin and Hughes Prizes.

It was at Cambridge that he first showed an interest in computation in general, and in Bessel and the allied functions in particular. From then until his death he developed methods of computing these functions, and in the *Philosophical Magazine* and in the *British Association Mathematical Tables* he tabulated Neumann functions, sines and cosines in radian measure (required for the rapid computation of transcendental functions), the Lommel-Weber function and the confluent hypergeometric functions. Astronomers in particular are indebted to him, for we have it on the authority of Dr. Comrie that the British Association Tables of Emden's Functions were calculated by methods suggested by Airey. Indeed, from 1911 he was an active member of the British Association Mathematical Tables Committee, in addition to serving as an editor of the *Philosophical Magazine*.

It is difficult to realise that during this period of high scientific productivity and selfless advisory labour Airey was the first headmaster of Morley Grammar School (1906 to 1912), the Principal of the West Ham Technical College, and from 1919 until his retirement in 1933 Principal of the Leeds City Training College. In each of these places he left his mark, and in an Address presented to him on his retirement in 1933 we read :

"Not only by your own achievements, but in your own addresses to us, you have held up the torch of learning—learning which can only be won by persistent and earnest effort.

"Serene in calm and storm, you have at all times steered a straight course, your actions characterized by sincerity of purpose and a love of what is right.

"You will live in our memories as a Principal and a friend whose words were few, and whose happy and kindly disposition shone out so brightly that even your reproofs were tinged with humour. Not least we shall cherish your memory because you showed us a religion based on simple faith and a reverential search for truth."

Airey was a D.Sc. of London (1915), and an Sc.D. of Cambridge (1926). He was elected a Fellow of the Society on 1931 June 12, and was also a Fellow of the Physical Society and the Edinburgh Mathematical Society. He died on 1937 September 16, being survived by his wife and a daughter.

THOMAS SANDERSON ANGUS was an enthusiast in all matters connected with nautical astronomy and the use of the sextant afloat. Born at Inverkeithing on 1851 January 24, Captain Angus, after leaving school, studied navigation at the Leith Nautical College. He was apprenticed to Messrs. P. Henderson & Co. of Glasgow in 1866 and served in two of their sailing ships before joining the P. & O. Company as fifth officer in 1881. He passed for master in the same year, and obtained his extra certificate for master four years later. He was given his first command, the *Canton*, in 1889, and commanded successively the *Ballarat* (1892–98), the *Britannia*, the *China*, and the *Macedonia*, the last named being the then largest unit in the P. & O. fleet. He retired from the sea in 1904 on his

appointment as Nautical Inspector in the Company, and from active service in 1922. In 1886 he had lost his right arm in an accident at sea.

Captain Angus was elected a Younger Brother of Trinity House in 1904. He served on the Admiralty Committee on Charts in 1912–13, and was the examiner in seamanship of the *Worcester* cadets from 1906 to 1926. He was elected a Fellow of the Society on 1924 February 8.

He died suddenly on 1937 March 5 at the age of eighty-six.

CHARLES EDWARD BARNS was best known to astronomers for his book, *1001 Celestial Wonders as Observed with Home-built Instruments*. In this book, which ran to a second edition and which he set up and printed in his own small printing plant (The Science Press), Barns described some of his own experiences as an observer and a maker of telescopes. Prior to his retirement to California in 1913 and to the appearance of this book, he had been a journalist and had served on the New York *Herald Tribune* under the notable editorship of James Gordon Bennett. He was known as the author of many stories and poems, as well as of scientific articles appearing in the *Herald Tribune*. He was elected a Fellow of the Society on 1929 January 11, and was in addition a member of the British Astronomical Association, the Astronomical Society of the Pacific, and the American Association of Variable Star Observers. He died on 1937 May 24 at the age of seventy-five.

ARTHUR FREDERICK BENNETT was by profession an engineer. The son of John Bennett, shipowner, of Grove House, Goole, he was educated at Bramham College, Yorkshire. On leaving school he was apprenticed to Messrs. Earles' Shipbuilding and Engineering Company of Hull, and rose in that firm to be superintendent of their Admiralty Contracts at Portsmouth. He was responsible for installing the machinery and making the trials of H.M.S. *Formidable* and H.M.S. *London*. Subsequently he became general manager of Messrs. Willans & Robinson of Rugby, and remained with that firm after their amalgamation with the English Electric Company. Finally he was made general manager and director of Richard Garrett & Son of Leiston, Suffolk, with whom he remained until 1934.

His interest in astronomy appears to have been kindled by the presentation to him in 1921, on the occasion of the amalgamation of Willans & Robinson with the English Electric Company, of a 3-inch refractor. Within a few years he had acquired a 6-inch Cooke equatorial, and to this from time to time new equipment was added, including cameras for stellar photography and, a few months before his death, a Synchronome Sidereal Clock. In his career as an observer the British Astronomical Association played an important part, and to their *Journal* he contributed his many observations of occultations, of comets and of the Sun and planets. He was elected Honorary Treasurer of the Association in 1931, and held this office from then until 1933, and from 1936 until his death. He was elected a Fellow

of the Society on 1925 February 13, and was also a member of the Institute of Civil Engineers and of the Institute of Naval Architects.

He died suddenly on 1937 May 14 at the age of sixty-six.

RICHARD EDWARD SYNGE COOPER was elected a Fellow of the Society on 1891 June 12. He was a grandson of E. J. Cooper, F.R.S., the founder of the famous private observatory at Markree Castle, but was intended by his father for the army. While at Cambridge he served for a time as an unpaid assistant at the Observatory, but finally abandoned both astronomy and an army career to become an engineer. He was trained as a civil engineer on the old London and North-Western Railway, and rose to be successively chief assistant on the Brighton Railway and chief assistant for the New Works of the London and North-Western. He retired in 1929, and after a long illness died on 1937 May 4 at the age of sixty-eight. He is survived by his wife, three sons and a daughter.

EDWIN BAILEY ELLIOTT played a vital but unassuming part in the development of Oxford mathematics. After taking first classes in Moderations and the Final School, he was elected to a Fellowship at Queen's in 1874. As a teacher he gave unsparingly of himself, not only to his more promising pupils, but even to those who were far from brilliant, and this unselfish devotion to teaching continued even after his election to the Waynflete Professorship and his transference to a Fellowship at Magdalen in 1892. After forty-seven years' service as tutor and professor he retired in 1921, being then elected Professor Emeritus.

At a period when research at Oxford was rarer than now, Elliott found time in the midst of his many teaching duties to produce a long series of papers in the *Proceedings of the London Mathematical Society*, in the *Quarterly Journal* and in the *Messenger of Mathematics*. He will be chiefly remembered, however, for his great work, *An Introduction to the Algebra of Quantics*. This book, though it deals with a branch of mathematics which at the moment is no longer fashionable, has been described by an authority as "a masterly exposition of results due to Cayley and Sylvester, and of those due to Salmon, MacMahon and Elliott himself." His last published paper, written at the age of seventy-five, gave what is generally regarded as the best proof of an important theorem in convergence. He was elected a Fellow of the Royal Society in 1891, and served for two years on its Council. For many years he was a member of the Council of the London Mathematical Society, and was its president from 1896 to 1898. He was elected a Fellow of the Society on 1893 June 9.

In addition to his research and teaching, Professor Elliott served on many University Boards and Committees. In particular, he was a member of the Board of Visitors of the University Observatory from 1889 to 1926, and served on both the Hebdomadal Council and the University Chest. To these various duties he gave that same painstaking care which characterized all his work, and the University owes him a great debt for his many years of administrative labour.

He died in Oxford on 1937 July 21 at the age of eighty-six, having been predeceased by his wife who had died only two months before.

SAMUEL FELLOWS died on 1937 July 3 in his ninety-fourth year. As a boy working in a South Staffordshire forge, the appearance of Donati's Comet of 1858 kindled in him a desire to know something of astronomy. With an initiative rare in a boy of that age, under those circumstances and at that time, he constructed a home-made telescope, and with this instrument saw for himself some of the wonders of the heavens. While still in the ironworks he attended a night school, and at the same time embraced every opportunity to increase his knowledge of astronomy. At the age of twenty-six he left the forge to become clerk, and subsequently departmental manager of Butler's Springfield Brewery, a post from which he retired in 1904.

He was elected a Fellow of the Society on 1889 January 11, and became one of the charter members of the British Astronomical Association on its foundation in 1890. He took part in expeditions organized by that body to observe the eclipses of 1896 August 9, 1900 May 28 and 1905 August 30, and at a meeting of the Association on 1905 October 25 described some of the results of his eclipse-observations with illustrations from his own photographs.

JOHN McDOUGAL FIELD was Astronomer to the City of Edinburgh. This post, the result of the transference by the Government of the old buildings on Calton Hill to the City in 1889, was first occupied by Sir William Peck, who had even before this date commenced those popular lectures in astronomy which became, when associated with the Calton Hill Observatory, an important feature in the intellectual life of the community. Field was one of Peck's first assistants, and on the death of the latter succeeded him as City Astronomer. Under Field's direction the usefulness of the Observatory as an educational centre was still further increased, and under his guidance thousands of school children were given their first introduction to astronomy.

Field played an important part in the Edinburgh Astronomical Society. He was one of its earliest members, a past president and a trustee of the Lorimer Bequest. He was elected a Fellow of this Society on 1908 January 10. He died on 1937 April 12 at the age of sixty, being survived by four brothers and one sister.

LOUIS NAPOLEON GEORGE FILON was born on 1875 November 12, his father being tutor to the Prince Imperial. He died on 1937 December 29, a victim (according to *The Times* of December 31) of the Croydon typhoid epidemic. He married Anne, daughter of Professor Godet, of Neuchâtel, and had one son and two daughters. He was successively student, demonstrator, lecturer, fellow and Goldsmid Professor of Applied Mathematics and Mechanics, at University College, London; his brilliant academic career included a period of research study, as an 1851 Exhibition Scholar, at King's College, Cambridge. He was a D.Sc. of the University of London,

in whose complicated government he played an active and valued part over a long period of years ; he became Dean of the Faculty of Science, a member of the Senate and of the Court, chairman of the Academic Council, and Vice-Chancellor (1933–35).

In a tribute in *The Times*, referring especially to Professor Filon's great services to the University of London (especially in connection with the new constitution introduced in the Act of 1926), his friend Sir Graham Little, M.P. for the University, wrote : "No name should be more honoured and cherished by the University of London than that of Louis Napoleon Filon. He was a man of fine presence, an excellent speaker and administrator, a most loyal friend, and although a doughty fighter, a generous opponent. He was deeply loved by all who knew him intimately, and to them and to the great University which owes so much to him his loss is indeed irreparable."

Another of the leading interests of Professor Filon, equally illustrating his great public spirit, was his long association with the University of London Officers' Training Corps, in which he held a commission from 1909 onwards. When the Great War broke out he volunteered for foreign service, and was with the British Expeditionary Force till he was invalided home in 1915 February, after which he undertook various forms of technical war service till his demobilization in 1919.

His wide knowledge of applied mathematics lay mainly in its classical fields, and particularly in elasticity and hydrodynamics and, later, in photo-elasticity ; in the last subject he co-operated with his friend and colleague, Professor E. G. Coker, with whom he wrote an important treatise on photo-elasticity. He served for many years on the Council of the London Mathematical Society, of which in 1923–24 he was Vice-President.

Few men are able to take so active an interest in university administration and other forms of public service, such as his work for the O.T.C., and yet continue, as Professor Filon did to the end of his life, to learn new branches of science, and to make valuable original contributions to knowledge. His later work showed the same analytical mastery and good judgment in the application of mathematics to problems of mechanics which in his younger days had won for him many academic honours, including (in 1910) election to the Royal Society, of which he later became a Vice-President. Moreover, his creative work was not limited to his own personal contributions to applied mathematics ; as a teacher and leader of a research school he influenced a long succession of pupils, among whom may be mentioned the late R. C. J. Howland, W. M. Shepherd, B. R. Seth, J. C. Dobbie, and in particular his former pupil and subsequent colleague, Professor G. B. Jeffery.

Professor Filon's wide scientific and administrative interests also embraced astronomy. He was keenly interested in this subject while still at Cambridge. Under the supervision of Mr. Hinks he photographed Swift's comet with a portrait camera attached to the Northumberland telescope, measured the plate, and discussed the errors in a short paper presented to the Society. He was also interested in Michelson's method of measuring

close double stars, later applied to star discs, and he contributed a paper to the Royal Society on this subject. When he succeeded the late Karl Pearson as Goldsmid Professor, he became Director of the observatories at University College and the school of astronomy which Karl Pearson inaugurated. His interest was further shown by the successful efforts he made for the encouragement of astronomical teaching and research in the University of London, leading to the establishment of the Observatory of the University in 1929. He was Director of this Observatory from its inception, and took an active part in its planning and equipment, though the actual work of astronomical teaching and observation, and a large degree of responsibility for the observing programme, were in the hands of the Wilson Observer, Mr. C. C. L. Gregory. Professor Filon had a long-standing connection with the Royal Astronomical Society, having been elected a Fellow on 1900 June 8; in view of the many claims on his time, it is not surprising that his attendance at the Society was infrequent, and that he never served on its Council. Since 1936 he had been a member of the Board of Visitors of the Royal Observatory, Greenwich. S. C.

SAMUEL FORSTER GRACE, known for his mathematical researches on tidal theory, died in 1937 April in his forty-third year, as the result of a wound received on the Somme in 1918 June. His academic career at Liverpool, though interrupted by the war, was brilliant, and was completed by work at the Sorbonne and the Collège de France while holding the 1851 Exhibition Research Scholarship. In 1921 he joined the teaching staff of the Department of Mathematics at the University of Liverpool, and commenced a period of brilliant teaching and sound research, now regrettably terminated in its prime.

The early part of his work, published in the *Proceedings of the Royal Society*, was concerned with the motion of solids in a rotating liquid. His researches on tides, the results of which were communicated to the *Geophysical Supplement*, have been described by Professor Proudman thus:

"These fall into three groups on the following subjects: (1) The analysis of observational data with the object of finding laws of internal friction in tidal currents, and the friction of the sea bottom. (2) The theoretical determination of the distribution of the tides over the Gulf of Mexico and the Bay of Biscay. (3) The dynamical explanation of the actual tides in narrow seas.

"All Grace's research was marked by excellent workmanship. He had a steady-going persistence and thoroughness and a capacity for hard work which carried him far."

Grace was elected a Fellow of the Society on 1930 April 11.

JAMES HARTNESS, whose death in 1934 at the age of seventy-three was recorded last year, played a distinguished part in many walks of life. Apprenticed at the age of sixteen to a Cleveland firm of machine-tool makers, he acquired experience in a number of such firms before coming to that of Jones & Lamont of Springfield, Vermont, at the age of thirty-two. With

this firm he was successively superintendent, manager and finally president, and to it he brought ideas which had long been maturing in his mind on the design of what is now known as the Hartness turret lathe. The manufacture of this precision lathe, as well as the design and construction of several varieties of automatic lathes, brought wide recognition to the firm and to himself. He held patents for over a hundred of his own inventions, which included, besides the previously mentioned lathes, designs for threading dies and for an optical gauge for testing screw-threads.

In addition to his professional career Hartness served his state and his country well. For six years he was chairman of the Vermont State Board of Education, he was chairman of the Committee of Public Safety and Federal Food Administrator during the War, and from 1921 to 1923 he was Governor of the State of Vermont.

To astronomers Hartness is best known for his design of the "turret telescope"—a telescope which owed its origin to his early interest in astronomy and to the rigours of a Vermont winter. This particular design is generally recognized to be optically the simplest of the various forms of fixed-view equatorial telescopes, which include the polar telescope (objective fixed in the bottom of the polar axis and fed by a polar heliostat, examples at Harvard and Yale), the Sheepshanks Telescope at Cambridge, and the Coudé Telescope of Loewy. Of these three main types the Coudé with its two reflections at fixed angles of incidence is optically superior to either the Sheepshanks or the polar telescopes with their single reflections at variable and possibly very high angles of incidence. In the Hartness "turret telescope," however, the same end is secured by a single reflection at an angle of incidence of 45°; in this telescope the polar axis is a capped cylinder, an opening in the side of which carries the declination axis, this latter axis being itself the seating for an ordinary 90° ocular. The telescope with its tube and objective outside is free to swing about this axis to any required declination, while the observer sitting inside a shelter and facing north, with his head in the polar axis, has a comfortable and very nearly stationary view of the object under investigation. Thus if following an object from the meridan west, he commences by looking horizontally to the west or left, and as the hour angle increases the eyepiece is slowly carried round by the polar axis until the observer is at six hours looking downwards. A 12-inch telescope to this design was constructed by Hartness in his home at Springfield, and its convenience in practice has been highly spoken of by many astronomers, including Professor S. A. Mitchell.

Hartness was president of the American Society of Mechanical Engineers and of the American Engineering Council, "the highest elective positions in the gift of his profession." Amongst other scientific and technical societies he was a member of the Aero Club of America, having won his pilot's licence at the age of fifty-five. He was elected a Fellow of the Society on 1916 November 10.

MAURES HORNER was one of the senior Fellows of the Society, having been elected on 1879 March 14. Until recent years he regularly attended

the meetings, and was a constant reader in the library. His caustic wit and humour were well known, and he delighted to refer to himself as the "enfant terrible" of the Society. Writing of him in *The Times*, "M. N." says :

> "His knowledge of astronomy, botany and all tree-lore, and geology, as well as archæology, was immensely wide, and he went on learning joyfully and eagerly to the day of his death. His visits are some of the best memories of my childhood. I shall always visualize him arriving to stay, armed with a stone hammer, a telescope and an aneroid, and specimens of stones and flowers collected on the way. To go for a walk with him or to look at the stars through his telescope opened new doors in one's mind. For he had the gift of sharing his knowledge in a way which made it a prelude to adventure."

He was the third son of the Rev. J. S. Horner of Mells Park, Somerset, where he was born in 1849 June 10. He went to Eton in 1861 with his twin-brother George, afterwards rector of Mells, and was in the XI which drew with Harrow and severely defeated Winchester. He left Eton to become a merchant in London. He died on 1937 January 17, just one year after his twin-brother George.

THOMAS CHARLTON HUDSON (born 1868 June 10) was the son of the Rev. William H. Hudson of Wimbledon, who wrote several books of mystical and religious poetry.

T. C. Hudson was elected a Fellow of the Society in 1898. At the City of London School, where he was educated, he shared the position of Head Boy with his friend (now Sir) Frank Delavigne. At Cambridge he was a scholar of Sidney Sussex College, and he early came under the influence of Sir J. J. Thompson at Trinity. After leaving Cambridge he served for a time at the Royal Observatory, Greenwich, and then joined Dr. Downing's staff at H.M. Nautical Almanac Office in the old days at Verulam Buildings, Gray's Inn. These were congenial surroundings, and his inventive genius soon led him to produce his Star-correction Facilitator, fully described in *M.N.*, **54**, 90, 1893. This was probably Hudson's first matured effort. This machine reduced to a minimum the labour involved in the preparation of star ephemerides. It may be justly regarded as the germ of the progressive movement which culminated some forty years later as shown by the sentence "Logarithms are no longer used in the Nautical Almanac Office," written in the preface by Dr. Comrie to the *Nautical Almanac* for 1935. At about this time he was asked to review what was then the standard book on Interpolation, written by Professor Rice of the American Ephemeris, and thereafter the subject fascinated him, with the result that in 1901 he published his improved method of "interpolation to twelfths" (*M.N.*, **62**, 17, 1901). Later by some score of years he became an enthusiastic student of Vectors, and, strengthened in this direction by his friendship with Silberstein, he has been known to halt at the most draughty corner of a busy station and by the aid of a rectangular box of matches to give an inquirer an initiatory lesson in Vectors Made Easy.

From long-sustained thinking was born his paper, "Concerning Ephemerides of Small Planets" (*M.N.*, 84, 585, 1934). This gives a good idea of the man himself—of his originality in ideas and in language, his disregard for tradition, of his readiness to apply his mathematics to astronomical difficulties and of his halting near the end with refusal to "deal with numerical examples." Three other mathematical papers followed as a continuation of this subject in *M.N.*, 85 and 89. In 1914, at the Napier Tercentenary Celebration, he read a note on "Critical Tables"—a labour-saving device which gives results true to the nearest unit at sight and yet without uncertainty. Such tables are now aids familiar to every computer.

In the Handbook of the Napier Exhibition there is at page 127 a clear account by Hudson of the Anti-differencing Machine (Burroughs) and its application to Heliocentric Longitudes by means of end-figure interpolation.

Hudson married, in 1904, Sarah Beatrice Brown of Thorpe House, Raunds, Northants, and had four children, of whom three survive. His wife, well known at our meetings, and by reason of her bright disposition and courage under difficulties very popular, died in 1930.

Hudson died at Saffron Walden a few days after being stricken with cerebral hæmorrhage, on 1937 May 19.

Throughout his life he was ever ready to dispute theological questions, and in particular those where he evermore

"Came out by the same door as in I went"

and now no more words concerning my wayward friend. F. R.

RICHARD INWARDS, son of Jabez Inwards, was born on 1840 April 22. He was trained as a mining engineer, and was employed by Messrs. Evan & Askin to manage mines at San Baldomero, Bolivia; and in Spain for the Manganese Company. He also managed the Iron Mine and Railway in that country, and reported on mining enterprises in Austria, Mexico, Norway, Portugal, South America and England.

In the eighties he happily became acquainted with the inventive genius, Professor David E. Hughes, F.R.S., which led to his attending from time to time the happy weekly luncheon parties of the Hughes' Coterie—consisting of J. Buckney, Conrad W. Cooke, Edward Clodd, Henry Edmunds, George Forbes, Sir Percy F. Frankland, Oliver Heaviside, A. E. Horton, Sir William H. Preece, Augustus Stroh and other notable men. For many years the Coterie met at the Horse Shoe Hotel, but when Frascati's opened a large table was reserved there every Wednesday for the luncheon. Inwards often blessed the day that he first met Stroh at one of these jovial gatherings, as they became very intimate and lasting friends. They had much in common, as Stroh was a mechanician of the highest order (having worked out Wheatstone's famous electric telegraph instruments, and later manufactured such instruments for the Government, as well as having invented a beautiful stereoscope, and a new violin), while about this time Inwards's principal recreations were mechanical and microscopical, producing beautiful models and the like in a workshop (fitted with a wonderful lathe) arranged

in his home. He lived not far from Stroh, and they were both members of the Camera Club.

The professional work of Inwards, George Forbes and some other members of the Coterie, often called for their services abroad, and on their return there was much rejoicing. A notable occasion was the return of Forbes from his Survey of the Cataracts of the Nile, for the Egyptian Government, in 1898. Inwards and the others were thrilled when Forbes described his remarkable experiences, particularly how on his return to Cairo the some 2000 negatives of important photographs he had taken were spoilt and practically ruined by the unskilful treatment by a local photographer! Forbes also humorously told us that he commenced his Report on the Survey by writing "There are no Cataracts on the Nile"!

The fact that Hughes during many of his last years was a Vice-President and Manager of the Royal Institution was much appreciated by Inwards, as he was able, whenever he wished, to attend the Friday evening Lectures there, and exhibit his models at the Conversazione that followed—one of them being a wood model of part of the great Pyramid (showing the entrance to it) that was much admired.

The following is a typical letter from Hughes to Inwards, dated 1896 June 7: "Many thanks for your kindness in sending me copies of your interesting paper on Meteorological Observations and Turner Lightning, I had already read these in abstract but have read them again in full. Turner's clear idea of the true form of Lightning is most interesting, and I believe he stands alone in being the only one which gave something new which photography has revealed to us. Hoping to have the pleasure of seeing you at the Royal Institution on the 19th, when Niagara is the order of the day, or rather night, and with thanks. Sincerely yours."

Inwards was the author of three notable books: the first, *Weather Lore* (1869), is a remarkable collection of proverbs, sayings and rules concerning Weather Wisdom; and following the Introduction are Sections on Time and Seasons; Sun, Moon, etc.; Wind; Clouds; Animals, etc.; Plants, etc.; the 91 pages of the work representing a great amount of research and discrimination. His second work, *The Temple of the Andes* (1884), sketches the history and traditions of the Peruvian people, with a fine account of the ruins of an ancient temple in Bolivia; it is beautifully illustrated by 20 full-page plates—accounts of the old Spanish writers being drawn upon. His *Life and Work of William F. Stanley* (1911) describes the career of his friend, the founder of the Company of Engineering Opticians, established in 1853—specialising in the manufacture of theodolites, levels, mining dials, drawing, meteorological and scientific instruments.

He was Joint Editor of the *Quarterly Journal of the Royal Meteorological Society* for about twenty years, and President of the Society, 1894–5.

He was elected a Fellow of the Royal Astronomical Society so long ago as 1861 February 8, and at the time of his death was the "Father" of the Society. For many years he was a regular attendant at its meetings where, with his long beard, he was a notable figure. In the two years 1895 and 1908

he served on the Council. From the annual meeting in 1931 a congratulatory telegram on the completion of his seventieth year as a Fellow was sent to him, and five years later he received the congratulations of the Council when his fellowship had extended over three-quarters of a century. He communicated three papers to the *Monthly Notices*, viz. (1) "Suggestion for an Observing Seat for Transit Instruments" (**44**, 100, 1884); (2) "On a Compensating Pendulum" (**49**, 13, 1888); and (3) "On an Adjustable Compensation for an 'Invar' Pendulum," (**71**, 173, 1911).

In recent years Inwards's bodily health kept him confined to his home, but he was mentally alert and enjoyed talking with old friends about experiences of the past. Unhappily, some four years ago his eyes commenced to suffer from increasing cataract, which ended in his vision being destroyed, but the dear lovable, loyal, modest friend kept wonderfully bright, and continued to enjoy chats with his friends. In August last year he had to remain in bed and still was able to talk freely, but this power gradually tapered off, and he lapsed into a state of coma from which he passed to his eternal rest on 1937 September 30, unmarried, and in his ninety-eighth year, seventy-six years after his election as a Fellow of the Society.

H. J. S.
T. E. R. P.

CHARLES EDWARD MONRO, Rear-Admiral R.N. (retd.), who died on 1937 January 19 at the age of seventy-four, claims attention as being the central figure in a series of operations in the years 1907 and 1908, instigated by the hydrographer, Admiral Mostyn Field, and carried out under the advice of Sir William Christie, then Astronomer-Royal, that resulted in a determination of difference of longitude between the observatories of Greenwich and the Cape of Good Hope. Details are given in *Monthly Notices*, **69**, p. 91, "Note on the Telegraphic Determination of the Longitude, Greenwich–Ascension–Cape," by Sir W. H. M. Christie, K.C.B., and in a publication of the Hydrographic Office, but it may not be out of place to give a brief summary.

At the beginning of the year 1908, Captain Monro, then in command of the surveying ship *Mutine*, went with Lieutenant Gibson to the Island of Ascension, taking with them Transit D, one of the five instruments of the kind belonging to Greenwich Observatory, a chronometer fitted with apparatus to record the seconds-beat on a small portable tape chronograph, and made observations to determine the error of the chronometer on local time. By the courtesy of the Eastern Telegraph Company, who joined the cables at Madeira and St. Vincent so as to make unbroken connection between Porthcurno in Cornwall and Ascension, signals were interchanged to find the difference between the time of the chronometer and the Greenwich standard clock which registered at Porthcurno through a line of the Post Office. The syphon recorders of the Company were used in all cases for the signalling operations. Applying the error of the chronometer found by Capt. Monro and Lieut. Gibson and of the Greenwich clock from the clock-book to the difference by signals, there resulted an

approximate value of the longitude of Ascension based on the standard observer at Greenwich. In 1907 September and October and in 1908 July and August, Capt. Monro and Lieut. Gibson spent some time at Greenwich, observing with Transit D to find their personal equation compared with the standard observer, and this being applied together with small corrections related to the signalling the definite longitude of Ascension was derived.

As to the Cape longitude, the difference between the time by the chronometer and the Cape standard clock was similarly found by interchange of signals on the same evenings as the difference with Greenwich, the cables being joined at St. Helena. Hence the difference Cape–Ascension was found, and subtracting Greenwich–Ascension from Cape–Ascension the result is the difference of longitude Greenwich–Cape as if determined by the standard observers at the two observatories and independently of the error of the chronometer at Ascension. It happened that Mr. Pett, the standard observer at the Cape, was in England in 1907, and he attended at Greenwich to make observations with the Transit Circle to determine his personal equation compared with the Greenwich standard observer, which being applied gave the result finally $1^h\ 13^m\ 54^s{\cdot}62$ E. The value adopted before that time was $1^h\ 13^m\ 54^s{\cdot}76$ E., and is now $1^h\ 13^m\ 54^s{\cdot}60$. In the year 1911 Capt. Monro published a small book, *The Portable Transit Instrument*, which is actually a precise description of Transit D, and his method of using it; a modest work which, however, received notice in a continental review.

This was not Monro's first visit to Greenwich, for when a lieutenant in 1890 he attended with other officers to have some instruction in transit observing, and it may be well to describe his career categorically. He entered the Navy in 1876 and joined the surveying branch in 1885 July. Between 1885 and 1900 he was engaged in surveys in the Mediterranean, the East Indies, the Pacific and West Indies, and in 1900 was appointed to command H.M.S. *Dart*, then in commission off the coast of Queensland. He was promoted commander in 1901 June, and in charge of the *Rambler* was engaged on surveys in British North Borneo and the China coast. His next ship was the *Mutine*, of which he took charge in 1907, when he was occupied in the determination of longitude above described. He was promoted to Captain in 1907 December. Two years later he was appointed Assistant Hydrographer, and in 1910 retired from active service in the Navy and became Professional Officer to the Harbour Department of the Board of Trade, afterwards merged in the Mercantile Marine Department of the same Board, in which service he acted as adviser on foreshores, pilotage, lights, etc., but during the War returned to naval service and took night duty at the Admiralty. He was promoted to Rear-Admiral, retired, in 1919 January, but continued his work for the Board of Trade until December 1927. An obituary notice in another place says that "Admiral Monro was a very able and clever hydrographic surveyor, and possessed an endearing personality which was reflected in the happiness and contentment of the ships which he commanded," a sentiment with which those who made his acquaintance at Greenwich will readily agree.

He was the second son of the Rev. H. G. Monro, sometime rector of Strathfieldsaye, Hants, and brother of Sir Horace Monro, formerly of the Local Government Board. He was at the school at Stubbington in Hampshire which specialized for entry into the Navy. In 1912 he married Isobel Haldane Murray, daughter of James Campbell, Esq. of Stirling, who died in the year 1917 leaving two daughters. Three years later Admiral Monro married Violet Mary, daughter of Colonel Vincent of the Central India Horse, and in 1928, after his final retirement, made his home in Wigtownshire, where he occupied himself in church matters and the Boy Scouts' organisations, living an active, useful life in spite of a concealed complaint of the heart from which he eventually died.

He was elected a Fellow of the Society on 1910 April 8. H. P. H.

WILLIAM EDWARD RAYMOND died on 1937 January 15 at the age of sixty-six, being survived by his widow and a son and daughter. For over fifty years he had been in the Public Service of the State of New South Wales as surveyor and astronomer. His career has been summarized by Mr. James Nangle, the Government Astronomer, as follows :—

Mr. Raymond entered the Public Service on 1885 September 5 as Field Assistant to the late Mr. Joseph Brooks, Director of Trigonometrical Surveys, Lands Department. He was engaged for thirteen years in fixing the positions of the main towns in New South Wales for map purposes. He also assisted in fixing the boundary between New South Wales and South Australia at Cockburn, near Broken Hill, and the boundary between New South Wales and Victoria near Coorowong, Monaro District. During a trigonometrical survey in 1888 he placed the present cairn on Mount Kosciusko.

In 1899 he was transferred to Sydney Observatory and placed in charge of the Time Service of the State. He was also in charge of, and made the meridian observations for, the great Astrographic Catalogue, a work which lasted over a period of thirty-seven years.

On the death of Mr. H. A. Lenehan in 1908, he was placed in charge of the Observatory and remained as Officer-in-Charge until 1912 when Professor W. E. Cooke was appointed to the position as Government Astronomer.

Mr. Raymond was the first person in Australia to make observations of Halley's Comet at its last return. This object was picked up on 1909 November 9 and followed till 1910 July by the use of an $11\frac{1}{2}$-inch refractor. Numerous double star observations were made with the same instrument.

Mr. Raymond made three observation trips in relation to eclipses of the Sun. He went to Flint Island under the leadership of Sir F. K. McClean in 1908; to Vavau, Fiji, under the same leader in 1911, and to Goondiwindi, Queensland, under the leadership of Professor W. E. Cooke, in 1922.

In 1926 Mr. Raymond made transit observations to determine the longitude of Sydney, using wireless telegraphy and taking Saigon as the base from which these determinations were made.

He was elected a Fellow of the Society on 1905 February 10.

BERNARD PAGE SCATTERGOOD was born in Leeds on 1862 May 18, the third son of Thomas Scattergood, surgeon. He was educated at Leeds Grammar School and Queen's College, Oxford. He married Edith Mary Ingham, who survives him. He had no children. He was an electrical engineer by profession, but being a man of wide interests and culture and a research student by nature, he took very seriously to work outside his profession.

Scattergood was led to undertake the genealogical research which occupied him for many years by his being asked to help his father in writing the life of Dr. Anthony Scattergood, the divine (1611–1687), for the *Dictionary of National Biography*. In 1916 the manuscripts dealing with the life of his direct ancestor John Scattergood, East India Merchant, covering the years 1698 to 1724, were discovered at the Public Record Office. These valuable papers he edited and had transcribed for the benefit of students of Indian dialects, of philology, social history, currency and economics and the trade of the early eighteenth century. He investigated and transcribed the early documents connected with the Lawes-Wittewronge family of Rothamsted, and he wrote a history of the Manor of Rothamsted and an account of the Wittewronge descent of Sir John Bennet Lawes, F.R.S.

Foreseeing the coming of the Great War, he trained himself in musketry much against his natural inclination ; he became an expert rifle shot and formed a rifle club. When war broke out he was too old for active service, but for two years was an instructor in musketry.

He was interested in astronomy from childhood, but only took up the subject in earnest on his retirement from business in Leeds and removal to Harpenden, to which he brought his transit instrument and where he set up an installation for receiving rhythmic time-signals and recording them on a chronograph. All this apparatus he afterwards presented to the Leeds University. In 1929 he wrote a paper on a method of determining the apparent orbit of a binary star from yearly observations of position. This method he believed to be new and simpler than similar methods that combine graphical construction with calculation. This paper was accepted for publication, but in a diffident mood characteristic of him he afterwards withdrew it. He left unpublished a well-written paper entitled "On the Principle of Minimum N.P.D. as applied to the Investigation of the Proper Motions of Circumpolar Stars and to the Correction of their Observed Mean Places." He analysed and compared the observed mean yearly places of Polaris from 1847 to 1925 and found what he believed to be evidence of an oscillatory movement in both latitude and longitude with a period of about thirty-seven years, suggesting the existence of a dark companion. Radial velocity observations had confirmed the existence of a companion but with a longer period. His mathematics was sound and his work was done with scrupulous accuracy, and it was a great disappointment when after years spent in this research he was told by the experts in statistics he consulted that the residuals were of questionable significance.

He died at Harpenden on 1937 January 10. He was a man of simple and unaffected charm. He was elected a Fellow on 1924 February 8.

C. O. B.

AMBROSE SWASEY, engineer, scientist, philanthropist, was born on 1846 December 19 at Exeter, New Hampshire, from one of New England's pioneer families, inheriting from them, and bringing to full fruition, the sterling qualities of that Puritan stock. He died at the old homestead near Exeter, after a long, useful and happy life, on 1937 June 15 at the age of over 90 years. While his formal education was confined to the elementary school at Exeter, his remarkable career is indisputable evidence that his real education continued throughout his life. Endowed with simplicity and nobility of character, with a sound body and brilliant mind and with a true sense of artistic values, along with mechanical ability of the highest order—a remarkable combination—it is not surprising that he earned the respect and affection of all who were privileged to know him, and that few men have left a wider circle of warm friends. Neither is it surprising that he was awarded the highest honours in the gift of his fellow-countrymen for his mechanical and scientific achievements and for his many benefactions to scientific, educational and religious organizations.

In 1865, in his nineteenth year, he entered on a three-year apprenticeship in the general machine shop in Exeter, where, a year later, he was joined by Worcester Reed Warner. The two apprentices boarded together and became warm and lifelong friends, this association subsequently developing into the world-famous firm of Warner & Swasey. After the two friends had completed their apprenticeship they started out to "make their fortune," journeying to Hartford, Connecticut, on 1869 May 24, where they were soon established with the Pratt & Whitney Company, builders of high-grade machine tools, and where they remained eleven years. Mr. Swasey was soon placed in charge of the gear-cutting department, where his mechanical genius rapidly developed improvements in methods, eventually leading to the first method of mechanically generating and cutting epicycloidal teeth. His first patent on improvements in protractors was granted in 1875, followed in later years by numerous others on turret-operating mechanism and other improvements in machine tools, and on optical-sighting devices and range-finders.

The two friends left the Pratt & Whitney Company in 1880 and started a machine-tool business in Chicago. Finding after a year, however, that the major manufacturing operations and the sources of supplies and of skilled labour were considerably nearer the Atlantic seaboard, they moved to their present location in Cleveland. Their great success in building turret lathes and other high-grade machine tools required almost continuous increase in their manufacturing facilities. Finally, in 1906, when their shop was enlarged to three times its former size, the partners decided to resist further expansion, in order that they might have, as Mr. Swasey put it, "time to travel, to look about us, to pass some time with our friends and to enjoy the good things of life." This very wise decision was followed, but with such a sense of balance and fitness, and with such helpfulness to worthy enterprises and to their friends and associates, as rounded their outlook and brought greater richness into their lives.

It seems obvious that the genius in design of Mr. Swasey, the great

interest in astronomy of Mr. Warner, and the splendid facilities of their organization for constructing tools and instruments of the highest precision, should form an ideal combination for mounting astronomical telescopes. This was especially true at this time when the rapidly increasing size of telescopes made it imperative that engineering methods rather than instrument-making practice should be applied to the mountings. Consequently, in the same year (1881) that they moved to Cleveland, a Warner & Swasey telescope was constructed for Beloit College, Beloit, Wisconsin, and in 1882 a dome for the Leander McCormick Observatory in Virginia. It was not, however, until 1885–86 that the first great test of Mr. Swasey's skill in telescope design came when the firm was invited to submit designs and tenders for the mounting of a 36-inch telescope for the Lick Observatory on Mount Hamilton, California. On 1886 May 29 Mr. Warner telegraphed Mr. Swasey that they had been awarded the contract for the mounting of the 36-inch telescope. Bids had been invited from another firm in America, and from one firm each in Ireland, France and Germany. Although the bid of Warner & Swasey, the firm with the least experience in telescope-building, and practically unknown in either Europe or America, was found to be considerably higher than the others, the design was considered so superior by the trustees that the contract was unanimously awarded to Warner & Swasey.

Construction proceeded rapidly, and in 1887 November Mr. Swasey travelled to Mount Hamilton to superintend the erection of the mounting on its foundation within the already completed dome. The 36-inch objective, made by Alvan Clark & Sons, was installed in the tube on 1887 December 31, and on the next clear night, 1888 January 3, the instrument was first tested. Mr. Swasey has told with considerable amusement that the focal length of the objective was six inches shorter than specified, and that Alvan Clark, junior, who had figured it, was much perturbed, enlarging on the difficulty and danger of changing it, and protesting that it would practically mean doing his work all over again. Mr. Swasey's kindliness soon overcame his love of joking, and he relieved Mr. Clark's anxiety by assuring him it could be remedied much more easily, and proceeded next morning to cut off six inches of the tube with a hack saw and refit the breech block. On the next fine night, January 7, the telescope was again tested before Captain Floyd, the Chairman of the Lick Trust, Mr. Swasey, Mr. Clark and Professor Keeler, the latter expressing himself as highly delighted with the performance of the instrument. The astronomical work done by this great telescope soon made it and the Lick Observatory famous, and firmly established the reputation of Warner & Swasey as builders *par excellence* and of Mr. Swasey as designer.

The next great telescope of Mr. Swasey's design was the 40-inch Yerkes refractor, the largest in the world, which was completed in 1897, the contract including also the dome and rising floor. The lines of this mounting followed generally those of the Lick telescope, with improvements suggested by experience. This instrument has also been successful, although the poorer astronomical climate in Wisconsin has made the Yerkes less efficient

than the Lick telescope. These two great refractors, the largest in the world, were, to a greater extent than the later telescopes, peculiarly Mr. Swasey's own design in both form and mechanism, and mark a great advance not only in accuracy and mechanical performance but in beauty and harmony of line. All of Mr. Swasey's designs, whether of machine tools, scientific instruments or telescope mountings, were characterized on the one hand by the simplest possible mechanism to achieve the desired purpose, by absence of purposeless ornamentation, by suitable strength and ruggedness where required, and on the other hand by smoothly flowing, pleasing line and harmony and beauty of form. Mr. Swasey was unequalled in combining engineering requirements with a real artistic sense of symmetry and proportion.

Besides a number of smaller refractors, the 26-inch Clark objective of the Naval Observatory, Washington, was completely remounted and equipped with a rising floor and new dome. This was the last of the large refractors of Warner & Swasey, as, with the change of emphasis from visual to photographic observations, with the great loss of light by absorption as the size and thickness increased, and with the great difficulties in making discs larger than 40 inches, the reflector became much more efficient than the refractor. Furthermore, the great success of the Mount Wilson 60-inch reflector convincingly demonstrated the superiority of reflectors in modern astronomical work.

Although work had been commenced on a 60-inch fork-type reflector for the Argentine National Observatory, the first large reflecting telescope constructed by The Warner & Swasey Company was a 72-inch with dome and accessories for the Canadian Government, erected near Victoria, B.C. The general form of the mounting and some original features, such as the exclusive use of ball-bearings on polar and declination axes, were laid down in the specifications, but the constructional and operating mechanism was designed by Mr. E. P. Burrell, Works Engineer of the Company, whose untimely death only preceded that of Mr. Swasey by four months. The beautiful lines of this mounting, unequalled in either earlier or later telescopes, and the symmetry and harmony of the design, were due to the engineering artistry of Mr. Swasey, who possessed a real genius in harmonizing the mechanical design with the beautiful and satisfying in appearance. This telescope set a new standard in accuracy, convenience and speed of operation, amply confirmed by the quality and quantity of the work produced in its twenty years of operation.

The 60-inch Argentine reflector, previously mentioned, was completed in 1922, and a 69-inch reflecting telescope with dome for the Ohio Wesleyan University at Delaware, Ohio, in 1923. The former was of the fork type along lines specified by Perrine, but the latter was similar to the 72-inch, although hardly so well proportioned, as such direct control over the general design of this and subsequent telescopes was not exercised by Mr. Swasey. There is now approaching completion for the McDonald Observatory of the University of Texas an 82-inch reflecting telescope, the largest and most advanced telescope yet constructed by The Warner & Swasey Company. The contract calls for the complete equipment, and consists of the mounting

and operating accessories, the grinding and figuring of the 82-inch mirror and other optical parts, undertaken for the first time by the Company, and the building and dome to house the instrument. This telescope has many original and valuable features, and is a masterpiece of mechanical design due to the genius of Mr. Burrell. Although Mr. Swasey exercised general supervision over the design of this and the Argentine and Delaware telescopes, he did not take so active an interest as in the 72-inch telescope, probably the finest example of his artistry.

Before passing to other aspects of his career, one characteristic remark of Mr. Swasey, who undoubtedly had much greater interest and enjoyment, latterly, in building telescopes than manufacturing machine tools, may be quoted as illustrating the combination of idealism and business instinct in his character. "We have never made money out of telescopes, but the money we have put in that end of our business has brought us invaluable returns in the form of contracts which have helped in the production and sale of turret lathes to which we look for profit."

The engineering genius and the architectural and artistic ability of Mr. Swasey do not begin to cover his claims to fame and to the admiration and affection of his fellows. His friends, and they were legion, for he made friends wherever he went, will rather remember him for his sterling integrity, his kindly and generous spirit, his keen sense of humour, a constant delight to his friends, and for his philanthropy as manifested in unnumbered benefactions for scientific, educational, charitable and religious purposes. Indeed, he gave away during his lifetime the major part of his well-earned wealth in accordance with his carefully made plan of earlier life.

It was only natural that a man of Mr. Swasey's genius should join the American Society of Mechanical Engineers in the year of its founding, and that he should find in this Society ample opportunity to develop his remarkable faculty of making warm and lifelong friends, especially among men of his own interests and ideals. As the years passed, his qualities of leadership and engineering ability brought him to the forefront of the Society, which never tired of doing him honour, while he never tired of helping them directly by his services and gifts and indirectly by his rapidly growing fame. He took an active part in the construction of the Engineering Building for the Engineering Societies, and was influential in persuading Mr. Carnegie to make the gift of this building. A splendid climax to his services to the Engineering Societies was his munificent gift of $750,000 to establish the Engineering Foundation for the specifically stated purpose: "For the furtherance of research in engineering or for the advancement in any other manner of the profession of engineering and the good of mankind." He served as President of the American Society of Mechanical Engineers in 1904 and was made an honorary member in 1916. In 1924 the Founder Societies awarded him their highest honour, the John Fritz Medal. He was awarded the Franklin Gold Medal in 1932 and became A.S.M.E. Medalist in 1933. The Society, in 1936, about the time of his ninetieth birthday and in the presence of the first recipient, Herbert Hoover, made him the only other recipient of the Hoover Gold Medal.

In addition to his endowment of the Engineering Foundation Mr. Swasey gave generously to religious and charitable organizations, and to educational institutions. In the latter category should especially be noted the foundation of a Professorship in Applied Physics in the Case School of Applied Science, held by his friend Dayton C. Miller, and his presentation with Mr. Warner to the same institution of a finely equipped observatory.

Dr. Swasey was married in 1871 to Lavinia Dearborn Cummings, who died in 1913. There are no children to survive him and carry on his name, but his memory will be kept alive by the great engineering and scientific products due to his genius and industry, and by the organizations and causes aided by his philanthropy. Above all, the memory of a noble character and of a true and lovable gentleman will be dearly cherished by those who had the privilege of knowing him. This sketch of his career cannot be more fitly closed than by a quotation from a citation by Philip Fox on the occasion of the presentation of the Washington Award in 1935 : "Dweller on earth for many years ; great in engineering achievements, in production and administration ; great in ingenuity and accomplishment ; great in breadth of views ; great in simplicity and forthrightness ; great in sympathies and spirituality ; great in appreciation of the essentials and obligations of life ; maker of machines, institutions and men ; a very noble gentleman, an engineer worthy to stand in the Washington succession ; a worker with helping hand outstretched and heart aglow for his fellow-men. I am persuaded that as he walked the earth among us, he walked with eyes uplifted to the eternal stars."

J. S. P.

ARTHUR HUISH WEBBER was born at Bourne, Lincolnshire, and died after a brief illness on 1937 March 15. By profession he was an artist, and had exhibited in both the Royal Academy and the Paris Salon. He was especially noted as a portrait painter.

He had long been interested in astronomy, and his equipment and the observatory in which it was housed were largely the work of his own hands. Apart from an interesting comment on the 1927 eclipse, which revealed the artistic eye and the ability to see colour, Webber confined himself to the observation of variable stars. He was a member of the Variable Star Section of the British Astronomical Association, and from the records of that Section was clearly an observer of more than average assiduity. He was elected a Fellow of the Society on 1922 November 10.

JAMES ERNEST GRANT YALDEN was one of the mainstays of the American Association of Variable Star Observers. Born in Brixton in 1870, he went with his parents as a boy to New York City. He received his primary education at Poughkeepsie, and graduated finally from New York University in 1893 as a civil engineer. After working for the Carnegie Steel Corporation for a time, he was encouraged to submit a plan for a technical school which was then being contemplated by the Trustees of the Baron de Hirsch Fund. His ideas were so well conceived that the

Trustees entrusted him with the task of founding this school, of which he remained superintendent until its recent absorption by the New York City school system.

Always fascinated by an outdoor life, and at the same time skilful with his hands, Yalden in his spare time became interested in yachting, and was the designer and builder of various boats, one of which, the *Hippocampus*, has figured in yachting literature. From yachts to navigation, and from navigation to astronomy were but short steps, and it was in 1919 that he joined the A.A.V.S.O. In this organization he was not only a consummate observer of variable stars, and the chairman of the Committee on Lunar Occultations, but he was a leading spirit in the work which went on behind the scenes and which determined the success of this complex organization. Whether it was in drawing the original charts for the identification of the variables, or in the design of telescope shelters for his brother members, the work was always done with that high technical skill and zest which characterized all his activities.

Yalden's knowledge of astronomy and his technical skill were responsible for his interest in sundials, and in this field he was one of the recognized authorities in the United States. He published a monograph on the subject for the Commission of Industrial Arts in New York, and was himself responsible for the design and construction of many beautiful sundials, notably that of the Biological Laboratory of Woods Hole, Massachusetts.

In addition to his membership in the A.A.V.S.O., of which he served as president in 1925, Yalden was a member of the American Astronomical Society and the American Association for the Advancement of Science. He was elected a Fellow of the Society in 1930 January 10.

Yalden died suddenly on 1937 February 22. He is survived by his widow.

PROCEEDINGS OF OBSERVATORIES

The following reports of the proceedings of observatories during the past year have been received from the respective Directors, who are alone responsible for them.

Royal Observatory, Greenwich
(*Director, Dr. H. Spencer Jones, F.R.S., Astronomer Royal*)

New Reversible Transit-Circle.—Preliminary observations have been in progress with this instrument. These were chiefly confined to observations of right ascensions. Early in 1937 it was realised that the instrument was giving R.A.'s systematically different from those of the FK3, the stars near the pole when observed either above or below pole appearing to transit too early as compared with equatorial stars (assuming the FK3 right ascensions to be correct). The order of magnitude of the error was half a second of time at 7° from the pole. But observations made by tapping transits across the fixed wires showed no appreciable deviations from the FK3 places. The trouble was thus located in the micrometer, and it persisted whether the motor drive was employed or whether the micrometer was hand driven. The effect was similar to that which would be produced if the moving wire lagged behind the micrometer screw by about 12 microns, corresponding to one second of arc.

If a defect such as this exists, it can be detected and measured independently of assumed star places by comparing transits of close circumpolar stars when observed at the same transit by the normal method of observation and by the special circumpolar method.* Micrometer lag can also be measured in a purely instrumental way (as was realised at a later date) by setting the motor to equatorial speed and driving it backwards and forwards so as to make the moving wire transit across one of the fixed wires, the observer recording each such transit by the tapping key of the three-pen chronograph.

Measurement of lag by observations of circumpolar stars gave 0″·7 as the lag of the wire behind the screw reading. But observations on the collimators showed no backlash in the ordinary sense, and it thus became apparent that the lag developed only when the micrometer was in continuous motion. After discussion with Messrs. Cooke, Troughton & Simms, the micrometer was detached and returned to their works at York on April 19 for examination and possible reconstruction.

* Described in *Cape Annals*, vol. xi, p. 277. The motor-driven wire is set to equatorial speed, and by means of the reversing gear the star is made to transit the wire alternately backwards and forwards in the field of view. The observer records each transit on one pen of a three-pen chronograph by means of a tapping key, and the other two pens record the clock time and the reading of the micrometer head.

The frame carrying the moving wire is constrained to move along a guiding rod by two sets of bearing surfaces, and motion in a direction perpendicular to the plane of the frame is prevented by a tailpiece which bears in a slotted slide. Messrs. Cooke, Troughton & Simms found that the guiding slide of the tailpiece required easing and that the guide rod was slightly convex to the eyepiece. These defects were rectified by the removal of very small amounts of metal, and at the same time similar defects in the zenith distance micrometer were removed in the same way. The micrometer was then returned to Greenwich and remounted, and it was found, both by observation of FK3 stars and by the purely instrumental test described above, that the lag was now negligible.

But before the dispatch of the micrometer to York another defect had been detected. On placing the telescope in successive positions 30° apart, and setting the moving wire either on one of the fixed wires or on a speck of dust on the horizontal wire that forms part of the Z.D. micrometer, it was found that the readings so obtained varied with the position of the instrument, the range of the readings amounting to about half a second of arc. This meant that the reading corresponding to the line of collimation would vary with the declination. This defect had been only slightly improved when the micrometer was returned from York, and, after a good deal of time had been spent in investigation, it was found possible to cure it by a simultaneous adjustment of the screws controlling the clamping of the guide rod to the main casting of the instrument, and those clamping the bearing surfaces of the wire frame to the guide rod. Subsequent tests showed that the lag has remained negligible.

The determination of the division errors of the circle has been continued. The errors of the one-degree divisions have been determined, the total range of these division errors amounting to 0″·38. Work is in progress on the quarter-degree divisions. The determinations have revealed the fact that accidental (as opposed to periodic) errors in dividing play an important part, and this will necessitate the determination of the error of each five-minute division on the circle.

The normal method of observing right ascensions with the instrument consists of the maintenance, by the observer using the differential motion, of bisection while the travelling wire is driven across the field by the motor at a speed approximately equal to that of the star. This method is available up to three degrees from the pole, but for transits of stars as near to the pole as this the continued maintenance of bisection becomes an undue strain on the observer. Accordingly, provision has been made whereby an audible signal is given in the observing house whenever a contact is registered on the chronograph. When observing near the pole this device allows the observer to relax his attention after the registration of a signal and to secure a fresh bisection shortly before the next contact is due. Its use can be extended to equatorial stars. The principle of making each contact used in the reductions an independent bisection is clearly important.

Airy Transit-Circle.—The total number of transits observed during the year was 6159, including 101 of the Sun and 84 of the Moon. The observa-

tion of stars in the zone 0° to 24° declination, begun in 1931, will be finished in the coming spring. A comparison between the right ascensions of the *First Greenwich Catalogue of Stars for 1925·0* and those of the FK3 was published in the *Monthly Notices* for November.

Cookson Floating Zenith Telescope.—The number of plates taken for the determination of the variation of latitude were :

January—19	May—25	September—24
February—27	June—17	October—16
March—19	July—13	November—29
April—10	August—19	December—4

In addition to these, seven plates were taken for the determination of scale.

The definitive discussion of the observations over the period 1911 September to 1936 June, referred to in last year's report, is proceeding.

28-inch Refractor.—The programme commenced in 1936 May is progressing satisfactorily. During the year 383 observations were made, distributed in separation as follows :—

Separation ...	$> 2''.0$	$2''.0 - 1''.0$	$1''.0 - 0''.5$	$< 0''.5$
No. of obs. ...	71	128	140	44

The comparison-image micrometer, mentioned in last year's report, was brought into use in September and is proving to be a valuable addition to the equipment. The increase in the number of stars observed with separation less than $0''.5$ which has resulted from its use is shown already in the figures given above.

A description of the instrument and some results obtained with it have been communicated to the Society.

An eyepiece interferometer, similar to that first used by Anderson in 1920,* has been constructed in the workshop and will be mounted on the telescope shortly.

Three binary orbits were computed during the year and the results published in the *Monthly Notices* for May and June.

Thompson 26-inch Refractor.—The number of plates taken for the determination of stellar parallax was 987. 1075 plates were measured and 28 parallaxes completed. The parallaxes of 28 stars were published in the *Monthly Notices* for November. 81 plates were taken through the glass for the determination of proper motions of stars in the Greenwich parallax list for which an interval of 10 years or more has elapsed since the first photograph. The probable error of the annual proper motions so determined is about $\pm 0''.003$.

Yapp 36-inch Reflector.—In continuation of the programme of colour temperature work using the slitless spectrograph, 131 comparisons of 52 stars with standard stars were secured. The programme comprises all stars of spectral types O, B and A north of 20° north declination and down to visual

* *Ap. J.*, **51**, 263, 1920.

magnitude $5^{m}.0$, together with some stars of the same spectral types south of 20° north declination and some stars of types Fo to Go inclusive. It involves some 240 stars, and should be completed in the spring of 1939.

20 plates have been taken at the telescope to determine the quantity ϕ_0' (see *Monthly Notices*, **96**, 832, 1936). On each of these plates a star was compared with itself, different exposure times being used and the light flux for the longer exposure being reduced by a coarse wire diffraction grating. The grating employed is one whose absorption is such that the exposure times for equal densities are as 1 : 25.

It is now the practice to determine the two quantities ϕ_0' and ϵ (see *Monthly Notices*, **96**, 828, 1936) for each batch of six dozen plates ordered from the makers.

New Slit Spectrograph.—The new slit spectrograph was delivered by Messrs. Adam Hilger Ltd. on April 8. After preliminary tests on its carriage it was mounted on the 36-inch reflector for test from June 17 until August 4, the colour temperature programme being interrupted over that period. Spectrograms of α Lyræ, α Cygni and other bright stars were obtained with the 3-prism and 1-prism dispersions.

The optical parts of the new spectrograph are made of ultra-violet glass combined, in the case of one of the camera lenses, with crystalline quartz. Uniform motion of the stellar spectra is effected by a plane parallel plate of ultra-violet glass, which is mounted immediately behind the slit, and which is rocked through a small angle by an electric motor and cam. The prisms are of 60° angle, and that employed in the 1-prism system is also the first of the train of three in the 3-prism system. The collimator lens, consisting of a single achromatic doublet of 2·05 inches aperture and 30 inches focal length, is also common to the two systems. For the single-prism system the camera lens is another achromatic doublet of 2·2 inches aperture and 12 inches focal length, and the resulting overall dispersion is 18·8 mm. from λ 3610 to λ 6560, with a tilt of 43°·5. The components of the camera and collimator lenses are constructed of ultra-violet flint and crown.

For the 3-prism system it was found that the combination of ultra-violet flint and crown did not permit of a very satisfactory aberrational correction under the required condition of small field curvature. The camera lens for this system has accordingly been constructed of ultra-violet flint and crystalline quartz. It consists of three components. Two of these, an ultra-violet flint and a quartz lens, form a contacted doublet, and the third component, which is of quartz, is separated by an air space. The combination is of 26·5 inches focal length working at $f/13{\cdot}2$ and, with a tilt of 2°·5, the dispersions in angstroms per millimetre are 107 at λ 6780, 39 at λ 4900, 19 at λ 4080 and 11 at λ 3540. Good definition is obtained without change of adjustment over the range λ 3600 to λ 6500.

The spectrograph body is supported within an outer casting, which also acts as the upper part of the temperature case. The temperature is controlled by a Cambridge Automatic Temperature Regulator. The flexure is satisfactorily small, the displacement of the image being 7 microns for a rotation of 180° in the most unfavourable position.

The instrument is provided with equipment for the Hartmann focal test and with half-aperture shutters for checking spectrophotometric calibrations.

Well-exposed spectra of α Lyræ with a slit width of 0·04 mm. were obtained under conditions of rather poor seeing, with exposure times of 300 seconds and 50 seconds with the 3-prism and 1-prism trains respectively.

Astrographic Equatorial.—4 plates of the eclipse and comparison fields at the time of the Solar Eclipse of 1940 October have been taken with a view to deciding as to the practicability of observing the Einstein displacement at that eclipse.

Plates of Eros are being secured for the purpose of correcting the orbit. Bad weather has interfered with observation during the present opposition. Up to the end of the year 8 plates were obtained on 3 nights. Observation will be continued for the remainder of the opposition.

Photoheliograph.—The Sun was photographed on 271 days at Greenwich and on 343 days at the Cape. Up to November 30 four days are not represented by either series, but plates for three of these days are available at Kodaikanal.

For the year 1937, the mean daily area of sunspots, corrected for foreshortening, was approximately 1750 millionths of the Sun's visible hemisphere, as compared with 1139 millionths for the year 1936. According to this provisional value, sunspot activity during 1937 is the highest for any one year since 1870–71.

Sunspot numbers have been supplied quarterly to Zürich for incorporation in the *Bulletin*. The appearance of large sunspots of area $\geqslant$ 500 millionths of the Sun's hemisphere has been reported to the Radio Research Station, Slough.

Spectrohelioscope.—Observations were made of the Sun's disc in $H\alpha$ on 180 days, and include (1) radial velocity measures of flocculi and prominences; (2) a search for bright eruptions especially in the region of sunspots; (3) photometric measures of flocculi and prominences. On 30 days, observations were limited by cloud, haze or mist to only a few minutes' scrutiny of the disc.

The measures of radial velocity, numbering 310, relate chiefly to absorption markings associated with sunspots. The largest component of radial velocity recorded during the year was -325 km./sec., shown by an absorption marking near a bright eruption on September 7.

During 1937, 86 bright eruptions were recorded as compared with 66 in 1936 and 25 in 1935. The occurrence of major eruptions has been reported immediately to the Radio Research Station, Slough. Quarterly returns are sent to M. d'Azambuja at Meudon, who compiles a collective list for inclusion in the Zürich *Bulletin*. The evidence for a close relationship between bright chromospheric eruptions and certain characteristic disturbances in the ionosphere, pointed out in last year's report, is greatly strengthened by a preliminary statistical discussion of the two phenomena (in addition to independent discussions made elsewhere) published in *Monthly Notices*, **97**, 594, 1937.

Photometric measures were made either with the lamp photometer

attachment to the spectrohelioscope, or with a calibrated wedge inserted directly in the field of view. The measures comprise intensities of 43 prominences, 116 bright flocculi and 30 dark flocculi. In most cases the measures determined the maximum intensity (*not* total intensity) of $H\alpha$ as compared with the intensity of the continuous spectrum 10 A. from the centre of $H\alpha$.* In 11 cases, however, the contour of the $H\alpha$ line given by flocculus or prominence was determined. A paper published in *Monthly Notices*, 97, 531, 1937, gives the results of visual observations of intensity of dark markings and of prominences observed in $H\alpha$ with the spectrohelioscope at Greenwich during 1936. Corrections to the observed contours of the line for finite resolving power and for scattered light are introduced.

Observations of Eros 1930–31.—The number of positions of Eros to be computed from measures made at Greenwich on plates taken at different observatories is as follows :—

Greenwich, astrographic . . .	205
Greenwich, 26-inch refractor . .	101
Oxford, 24-inch refractor . . .	49
Cape, 24-inch refractor . . .	558
Yale, 26-inch refractor . . .	63
Johannesburg, 10-inch Triplet . .	237
Melbourne, astrographic . . .	106

The measures on the Greenwich and Oxford series of plates have been completely reduced and the resulting positions of the planet Eros compared with Dr. Witt's ephemeris. These results are in good accordance. Considerable progress has been made with the large number of plates still to be dealt with, attention being given first to those taken at the Cape with the 24-inch Victoria telescope. The observed R.A. and Dec. of Eros, depending on final star places, have been computed for all the plates taken up to 1931 March 31 (478 positions), and the computations up to January 31 (138 positions) have been checked. The computation of the ephemeris positions for this series of plates is in hand.

The standard co-ordinates of the Reference Stars, based on the final star places, have been computed and examined for all the plates taken at Yale, Johannesburg and Melbourne.

Reference Stars.—The list of corrections to be applied to the places of the Primary Reference Stars given in *Astronomische Nachrichten* 5781–2 and 5852–3 has been completed. These corrections are based on the residuals obtained from the Greenwich and Cape series of photographs for Secondary Reference Stars, together with corresponding corrections obtained at the Cape, Bergedorf, Leipzig and Lick. The several series have been combined together, with weights in accordance with the number of plates on which each depended.

The Catalogue of Final Places of Secondary Reference Stars has also been completed, the positions depending on the places obtained from the

* In the case of flocculi the comparison reading refers to a closely adjacent part of the disc. For prominences it was taken at the centre of the disc.

Greenwich and Cape series of plates combined with results obtained at Bergedorf, Leipzig and Lick.

The Catalogue contains the places of 5624 stars arranged in zones of declination.

The list of corrections to the Primary Reference Stars and the Catalogue of Final Places of Secondary Reference Stars have been published in *Memoirs of the R.A.S.*, vol. lxv, pt. 4. The typewritten copy for press was prepared at the Royal Observatory and the Memoir printed by the Replica process.

Nautical Almanac Office.—The normal work of the office has progressed steadily towards overtaking arrears in the publication of the *Nautical Almanac* and the *Abridged Nautical Almanac*. Both *Almanacs* for 1938 were published in May, three months earlier than in the previous year, and it is anticipated that the 1939 editions will show a further gain of two or three months.

The main addition to the normal contents of the *Nautical Almanac* has been the provision of *Occultation Reduction Elements*, which were given for both 1937 and 1938 in the *Almanac* for 1938, and which will in future be a standard feature. In order to explain in detail the new method of reduction of occultations, using the newly published elements, a separate supplement to the *Nautical Almanac* for 1938, *The Prediction and Reduction of Occultations*, was published in August. The prediction of occultations for 59 stations covering practically the observing world (excluding the United States), and the calculation of the reduction elements now takes a large proportion of the time devoted to the preparation of the *Nautical Almanac*, and the opportunity was thus taken to give in the supplement a complete description of the work that the office does in this connection. In particular, the specially designed occultation machine, which has again been of invaluable service in examining 2350 stars and yielding approximate times for 4450 occultations visible from 59 stations, was described and illustrated for the first time.

The copy for the second volume of planetary co-ordinates referred to the equinox for 1950·0, containing data for the years 1940–60, together with those for Uranus and Neptune for 1800–1900, has been completed and will shortly be sent to press. A start has been made in the calculation of the perturbations of Comet 1933 *f* (Whipple) by several different methods for purposes of illustration, and considerable progress has been made with the first integration using Cowell's method.

Preliminary negotiations on and investigation into the change over to the FK3 fundamental system of star places, and the publication of a separate volume of apparent places of stars, have been entered into with the other *Almanac* offices, and general agreement has been reached. The change will take place in 1941.

At the request of the Air Ministry, the office has undertaken the publication of an *Air Almanac* specially designed for use in air navigation by astronomical observations. For the time being this *Almanac* is being issued quarterly.

Further to assist air navigation, Altitude Azimuth tables for the rapid determination of position lines from astronomical observations are being

prepared to the general requirements of the Air Ministry. The complete tables will occupy 12 volumes, each of approximately 210 pages. Copy for the first of these volumes is rapidly approaching completion.

A National Accounting Machine, Class 3000 with six registers and decimal adding mechanism, and a Brunsviga 20 Calculating Machine have been added to the equipment.

Clocks and Time-Service.—During the year observations for clock error were made on 101 nights. The small reversible transit which had been in use for this purpose since 1935 July was found to have developed worn pivots leading to erratic readings of the striding level. The pivots, which were of soft metal, have now been turned down and fitted with steel collars by Messrs. Cooke, Troughton & Simms. The irregularities have thereby largely been removed. During the period of alteration (September 10 to November 27) a similar instrument was employed for time observations. No discontinuities were apparent. The duplicate instrument is now also being fitted with steel collars on its pivots.

The time-service has been maintained. Some minor alterations have been made to the Rugby transmitter and relay apparatus in order to secure a higher standard of regularity throughout the rhythmic series of signals. Corrections have been obtained and published to the signals transmitted from Nauen and Bordeaux and (from March 1 onwards) to the Paris F.L.E. signals sent out at $9^h\ 30^m$ U.T. Regular determinations of the lag of the wireless time-signal recorder have been made by obtaining simultaneous film records on a cathode ray oscillograph and the time-signal results have been corrected accordingly.

A change has been made during the year in the method of employing the free pendulum clocks. It was previously the practice to use one (sidereal) clock as standard and (in effect) to plot its errors as deduced from the astronomical observations against the time. Each night's work with the small reversible transit gave a point on the diagram, and a smooth curve was drawn through the points which was taken to represent the real errors of the standard clock. Instead of continuing to employ one clock only as standard, it is now the practice to form a "mean clock" by averaging the readings of as many clocks as possible selected from the Shortt free pendulums Nos. 3, 11, 16, 40 and 49, together with the Shortt free pendulum clock at the National Physical Laboratory whose intercomparisons with the Greenwich clocks are available from the observations at Greenwich and at Teddington of the Rugby signals.* It is found that using the "mean clock" the smoothing of the observed points approximates more closely to a straight line over periods of the order of a month, and the provisional supply of time during periods of cloudy weather is rendered much more certain.

During the year it became apparent from an examination of the impulsing of the free pendulums that the impulse wheels were not all in poise, and that there was indication of excessive friction in the bearings. Shortt No. 11 was dismounted and fitted with a new impulse wheel. This clock is at present

* The N.P.L. clock is included on the grounds that, not being affected by influences local to Greenwich, it provides a useful check.

undergoing adjustment. It is proposed shortly to take the same action with regard to Shortt No. 3.

Shortt No. 40, which, as was mentioned in last year's report, was the gift of Mr. H. R. Fry, has been running with the photo-electric equipment for taking time directly off the free pendulum. A slight alteration has been made to its slave and the clock is now performing satisfactorily.

The equipment will be strengthened in the near future by the addition of a quartz crystal oscillator clock, which is now under construction at the National Physical Laboratory. It has been found that quartz oscillators are stable over limited periods of time to the order of $0^{s}.001$ per day, and the provision of one at the observatory should be of great help in detecting sudden changes of rate in the free pendulums and smoothing their short-period erratics. Provision has already been made for the accommodation of the new clock.

Printing.—The complete volume and the separate parts of *Greenwich Observations* for 1935 are about to be distributed. Good progress is being made with the printing of the *Observations* for 1936.

Staff.—Dr. R. v. d. R. Woolley resigned the post of Chief Assistant on June 1 prior to taking up the appointments of Chief Assistant at the University Observatory, Cambridge, and John Couch Adams Astronomer in the University of Cambridge. His place has been filled by Dr. R. d'E. Atkinson, formerly of Rutgers University, New Jersey.

Mr. C. R. Davidson retired on August 31. The vacant assistantship thus created has been filled by the appointment of Dr. A. Hunter.

During the year the organisation of the *Nautical Almanac* Office, which is now a part of the observatory, has been completely revised and the staff considerably augmented to meet the additional work undertaken on behalf of the Air Ministry. Miss F. M. McBain has been appointed an Assistant and Mr. W. E. Candler a temporary Assistant.

Miscellaneous.—Senhor J. A. Madeira of the University Observatory of Coimbra, Portugal, spent from July 17 to August 9 studying the work of the observatory.

Mr. A. H. Samaha, Chief Assistant of the Helwan Observatory, Egypt, was at the observatory from November 15 to December 9 studying the work in general with particular reference to spectrophotometry.

Royal Observatory, Edinburgh

Professor Sampson retired on September 30 after nearly twenty-seven years' directorship, during which the instrumental equipment has been modernised.

Observations for the determination of the clock correction have been taken with the transit-circle, and the morning wireless time-signals from Bordeaux, Rugby and Hamburg have been registered on each weekday. The daily checking of the barometer, thermometer and arc of the four

standard clocks has been continued, as well as the comparisons of the clocks on the micro-chronograph.

In the East Dome the programme has consisted of photographing stars having variable spectra, the quartz spectroscope being used in combination with the 36-inch reflector.

In the West Dome photographs of fields in the search for variables in Kapteyn's selected areas 2 to 19 has been continued, using the 10-inch camera. Pairs of plates are examined in the Blink microscope, and two papers giving a summary for areas 2, 3 and 4 have been communicated to the Society. Several stars of rather large proper motion have also been detected.

With the solar spectroscope, plates were obtained on ten days to determine the Sun's equatorial velocity of rotation. The plates have been measured in two positions in the Hilger micrometer.

Mr. Samaha, of the Helwan Observatory, worked at the observatory from 1937 December 16 to 1938 January 7.

Royal Observatory, Cape of Good Hope
(*Director, Dr. J. Jackson, H.M. Astronomer*)

Reversible Transit Circle.—Observations were continued of a list of 5373 stars, including all Boss and Backlund-Hough stars south of declination $+35°$. As the observation of these stars was only commenced in 1936 October, it was possible to make rapid progress with the fresh catalogue, and during the year 15,490 transits were observed. These include observations of the Sun on 206 days, Venus on 141 days and Mercury on 79 days. The exterior planets, including Vesta, were observed two or three times per week when they crossed the meridian during the evening hours of observation.

Completion of the copy for press of a catalogue of 8400 stars south of declination $-30°$ and 3267 zodiacal stars observed in the years 1925 to 1932 is still held up for the publication of the Albany General Catalogue, which will give the proper motion of many of these stars. The proper motion of the others will then be determined.

All the observations of a list of 7415 stars between the equator and declination $-30°$ observed in the years 1932–36 have been entered in the ledgers, and the reduction to 1935·0 is nearly complete. The periodic error in the system of Boss's right ascensions has been determined, and the result agrees closely with previous determinations.

These two catalogues are being reduced to the epoch 1925·0.

Eight-inch Transit Circle.—The observation of standard stars for the Zone $-35°$ to $-40°$ was completed early in the year, and in June the observation of standard stars for the zone $-52°$ to $-56°$ was commenced. The total number of observations with this instrument was 1341. The observations for the zone $-35°$ to $-40°$ have been ledgered and completely reduced to 1950·0.

Photographic Zone Observations. (a) *Zone* $-30°$ *to* $-35°$.—All the

plates have been measured. There are approximately 12,500 stars which have been measured in both the direct and reversed positions on each of two overlapping plates. The differences between the measured co-ordinates and the standard co-ordinates computed from previous catalogues have been analysed, and the corrections to be applied to the measures have been deduced. The results for the whole zone agree closely with those derived from the first 3000 stars.

(b) *Zone* $-35°$ *to* $-40°$.—The stars to be measured have been selected from Cordoba C, Perth Astrographic Standard Stars and the Cape Photographic Durchmusterung. This appears to be one of the worst observed zones in the sky, and the selection of stars for measurement has taken up a good deal of time. The positions of the stars from the catalogues named have been reduced to 1950·0 as far as R.A. $18^h\ 30^m$. The computation of standard co-ordinates has been completed and checked to R.A. $6^h\ 30^m$. The first 24 plates to R.A. $4^h\ 25^m$ have been measured and reduced. The earlier hours of R.A. have a very low star density.

(c) *Zone* $-52°$ *to* $-56°$.—A working list for this zone has been prepared. Each plate will extend 30 minutes in R.A., so that the interval between the plate centres will be 15 minutes.

Cape Astrographic Zones $-40°$ *to* $-52°$.—The copy for press of a catalogue of 20,554 faint stars in this zone has been completed. It contains stars of the C.P.D. of magnitude 9·1–9·5, and in addition 2432 fainter stars for which a proper motion exceeding 5″ per century was found when the plates were measured. The catalogue gives the following data: position, precession and secular variation for 1900·0, photographic magnitude, proper motion and spectral type. Only about a quarter of the stars are contained in the Henry Draper Catalogue, but through the co-operation of the Harvard Observatory the number of spectra was increased to 18,403. At the same time the spectra of 1866 stars in the Zone Catalogue (to magnitude 9·0 C.P.D.) were determined, making the spectral data for that catalogue nearly complete. Between the two catalogues we now have data for 41,397 stars in the zone $-40°$ to $-52°$, with spectra for 38,713 stars. The laborious work of identifying the faint stars on the spectrum plates at Harvard was greatly accelerated as the result of a grant of £80 from the Spencer Bequest of the Society.

Astrographic Telescope.—The following photographs were taken :—

2 plates of the 1940 eclipse field.
22 plates of 21 open clusters south of declination $-30°$.
4 plates of Kapteyn Selected Areas in declination $-45°$, for photometric purposes.

Wide Angle Lens.—Four plates of open clusters and 3 plates for photometry were taken. Preparatory to work in the Zone $-52°$ to $-56°$ a new scheme for fixing the position of the plate centre has been arranged. The position of the plate in the plate-holder is fixed by a star-like image on the plate (near its centre) made through a small hole in a metal plate which fits over the plate-holder in a definite position.

Victoria Telescope.—The instrument was in use for the determination of stellar parallax on 254 nights. 3476 plates were secured, of which 7 were for proper motion in declination. The number of plates measured was 2396 for parallax and 15 for proper motion. 141 plates were rejected as unsuitable for measurement, and 3156 remain in hand for measurement.

The parallaxes of 86 stars were published in *Monthly Notices* for November. This brings the total to 836 since observations were started in 1926. The parallaxes of a further 18 stars have been determined. The list published includes the three very bright stars Sirius, Canopus and Antares. The parallax exceeds 0″·100 for seven stars, several of which are well known.

The details of the parallax determination of 202 stars have been published in *Cape Annals*, vol. xiv, part iii. Proper motions in declination for these stars are also given.

97 plates with exposures ranging from 5 minutes to 2 hours have been obtained of 87 open galactic clusters south of −30°.

Photometric Telescope.—As the equatorial mount, which carries the photometric lenses, was originally constructed for visual observations, the slow motion in R.A. was unsuitable for photographic work. A new electric slow motion has been fitted. A number of diaphragms and a diffraction grating have been constructed.

Numerous focus and trial plates have been obtained with both the photographic and photovisual lenses. A number of plates have been measured in the Schilt photometer which has been overhauled and brought into active use.

Plates with a minimum exposure of 1 hour have been obtained in 12 regions south of −50°. It is planned to cover the whole of this part of the sky with similar plates, 41 in all being required.

7-inch Telescope.—This telescope which was formerly used by Innes for the observation of double stars has been remounted on a Dallmeyer equatorial stand in the dome which until recently contained the 6-inch refractor. A new slow motion in R.A. has been fitted. The instrument is mainly used for observing occultations.

Occultations.—The number of occultations observed in 1937 was 46, of which 7 were reappearances. The observations for 1936 were published in the *Monthly Notices*.

Photoheliograph.—729 plates of the Sun were taken on 343 days, including 29 plates for the determination of position angle and one plate exposed during the partial transit of Mercury on May 11.

A new focussing screen and finder have been fitted, the instrument rebalanced and the old clockwork drive substituted for the synchronous electric drive which had not sufficient reserve of power.

Mr. T. R. Miller, the instrument maker, retired in May. His unusual ability in the design and construction of instruments of precision has been of the greatest service to the Observatory over a period of thirty-nine years.

Armagh Observatory
(*Director, Dr. E. M. Lindsay*)

The Directorship has been vacant for the greater part of 1937. The routine duties of the observatory were carried on by Mr. Reseigh, the Meteorological Assistant. The present Director took up duties in 1937 November.

Cambridge Observatory
(*Director, Sir A. S. Eddington, F.R.S.*)

A number of alterations in the buildings and instruments have been carried out. In the main building accommodation has been improved by the removal of the large stone pier which occupied the centre of the mural circle room. The mural circle itself (Troughton & Simms, 1832), together with some smaller historical instruments, has been presented to the Science Museum at S. Kensington. In the Northumberland Equatorial the weight-driven clock has been replaced by a synchronous motor drive; the object-glass has been refigured by Mr. Hargreaves; and the micrometer has been repaired and supplied with new eyepieces. The dome of the Thorrowgood Equatorial has been remounted on an improved system, and a more satisfactory illumination has been provided.

The results of photo-electric observations of the light curve of Algol, 1932–36, have been published by Dr. Smart (*M.N.*, 97, 396). The photo-electric work is now being directed mainly to a study of the degree of constancy of the light of dwarf G stars. If it is true that the Sun's radiation is subject to irregular variations of the order 1 or 2 per cent., we should expect to find similar irregularities in some of the stars which most closely resemble the Sun. Each dwarf is compared with two giant G stars.

Dr. Woolley has begun a programme of measures of double stars. The following observations have been obtained with the Thorrowgood :—

Separation	$> 2''$	$2''$ to $1''$	$< 1''$
Pairs	16	19	11
Measures	43	49	29

The following research students have worked at the observatory: M. Krook, Isaac Newton student, has been engaged on astrophysical problems, especially on the correction of the ionization formulæ for the effects of deviation from thermodynamic equilibrium in the outer layers. G. L. Clark, Isaac Newton student, has reinvestigated the problem of n bodies in relativity theory in connection with Levi-Civita's recent calculation which predicts that a double star will undergo a secular acceleration in the direction of the periastron. H. C. Corben and D. S. Evans have been working on relativistic quantum theory and astrophysics respectively.

Dr. W. M. Smart, who had been Chief Assistant since 1919, resigned on March 31 to become Regius Professor of Astronomy in the University of Glasgow. He was succeeded on June 1 by Dr. R. v. d. R. Woolley.

Solar Physics Observatory, Cambridge University
(Director, Professor F. J. M. Stratton)

Staff.—Dr. R. O. Redman and Mr. E. G. Williams have resigned on appointment to the staff of the Radcliffe Observatory, Pretoria. They have been succeeded, as Assistant Director and First Junior Observer respectively, by Dr. A. D. Thackeray and Dr. H. Brück. Dr. A. Beer has left on appointment to the staff of the University of London Observatory, and Mr. E. G. Shirley of the Radcliffe Observatory staff has also ceased to work at the observatory. Mr. M. Krook, Isaac Newton Student, and Mr. W. S. Tai have been engaged in research at the observatory.

Instruments.—A cœlostat with secondary mirror, made by Sir Howard Grubb, Parsons & Co., has been installed for use with the spectrohelioscope. The spectrohelioscope and spectroheliograph are now no longer fed from the same siderostat, and the two instruments can be used simultaneously in the study of changes of solar eruptions accompanying changes in the ionosphere. The slits of the spectroheliograph have been polished on glass plates figured to the right curvature—a method suggested by Mr. Evershed. Uniform images with narrower slits can now be obtained, a feature of great importance in the proposed photometric study of *Hα* eruptions. In the *Hα* spectroheliograms the second order spectrum is now used in place of the first order.

Motors have been installed for controlling the focussing of the McClean spectrograph and for the movement of the solar image across the slit.

A two-prism spectrograph working at *f*/4, designed by Dr. Redman, has been assembled and mounted on the 3-foot Common reflector. Thermostatic control is being applied.

A calibrating spectrograph has been designed with a stepped slit in place of the wedge formerly employed. For plates of higher photographic densities than those for which the microphotometer is most suitable a modification of the microphotometer has been adopted, the electrometer being replaced by an amplifier.

Solar Work.—Photographs of the disc in K_{232} light were secured on 82 days, in *Hα* light on 61 days ; photographs of the limb in K_{232} light were secured on 61 days, in *Hα* light on 31 days. Visual observations with the spectrohelioscope were made on 44 days, chiefly after the installation of the new cœlostat.

Experimental photographs have been taken of the Sun through a silvered quartz lens fed from an aluminized plane mirror and transmitting a narrow band in the ultra-violet, 3210–3230 A. To secure a larger image an aluminized concave mirror is being used, and the silvered quartz lens is being replaced by a quartz flat silvered by sputtering.

Results of accurate measurements of the profiles of six strong lines in the

solar spectrum have been communicated to the Society (*M.N.*, **97**, 552). The work is being continued on the same lines in sunspot spectra; the central intensities for the metallic lines come out very nearly the same for spot and disc.

The flash spectra obtained in Hokkaido at the solar eclipse of 1936 June 19 have been intensively studied and the results communicated to the Society (*M.N.*, **97**, 672).

Stellar Work.—227 spectrograms of 29 stars were secured on 147 nights with the Newall 25-inch refractor. The stars specially studied were γ Cassiopeiæ, β Lyræ, ζ Aurigæ, δ Cephei and N Herculis 1934. In addition, some spectrograms of stars with wide absorption lines were secured and sent to Professor Carroll, Aberdeen University, for the determination of stellar rotation by the method developed by him. A study of the intensities of absorption lines of widely varying excitation potential in stars of types A to K has been commenced, with special attention to the changing relative strengths of resonance lines of neutral and ionised elements.

A spectrophotometric study of the bright bands and accompanying absorptions of β Lyræ has been commenced, and a study of the equivalent widths of selected lines of δ Cephei at different phases in the light cycle. The eclipse of ζ Aurigæ in 1937 April was observed so far as weather conditions allowed, and a paper has been prepared for publication on the material obtained, supplemented by spectrograms from the Norman Lockyer Observatory, Sidmouth.

The measurement and reduction of the spectrograms of N Herculis 1934 is nearly complete. A further paper on the first phase of the Nova's development has been communicated to the Society (*M.N.*, **97**, 231). The spectrograms obtained of N Lacertæ 1936 and N Aquilæ No. 1, 1936, have been measured and prepared for publication.

The programme of photometry of extra-galactic nebulæ has been terminated, and the results are being prepared for publication. An investigation into systematic errors has shown that the observed distribution in surface brightness is not appreciably affected by scattered light, except at points very near to the nucleus.

Other Investigations.—A programme of co-operation with the radio investigators working close to the observatory has been drawn up, so that the relation of the fade-outs to bright solar eruptions may be studied in more detail. A list of 2000 lines and the ascertained true levels of the spectrum of *Fe*II is now going through the press.

Durham University Observatory
(*Observer, Mr. Frank Sargent*)

Work on variable stars has been carried on as in previous years. Observations have also been made on Nova Lacertæ (1936 June), Nova Aquilæ (1936 September) and Comet Whipple.

The observatory is now under the control of the University Senate.

Imperial College Observatory, South Kensington
(Director, Assistant-Professor H. Dingle, D.Sc.)

The observatory has been concerned, as usual, mainly with courses of instruction to students. The work on solar spectrum line profiles, mentioned in the last report, has been begun, and a scheme of work has been prepared, to be carried out when the hours of sunshine become more numerous. In the meantime, laboratory work is in progress on the profiles of absorption lines, for comparison with those of solar lines when obtained.

The grazing incidence vacuum spectrograph is at last almost completed, and a grant from the Spencer Bequest to the Physical Society has enabled a start to be made on the construction of a lithium fluoride prism spectrograph of high dispersion for the Schumann region. With these instruments it is hoped to investigate band spectra of astrophysical interest.

Tables of known band spectra, arranged in a form convenient for reference, are in preparation. These, when published, should make less frequent the attribution of observed bands to wrong sources, and the repetition of "discoveries" of familiar systems, which now too often occur.

University of London Observatory, Mill Hill, and University College Observatory
(Wilson Observer, Mr. C. C. L. Gregory, M.A.)

On December 27 the Observatory lost its Hon. Director through the death of Professor L. N. G. Filon, C.B.E., F.R.S., who was a victim of the Croydon typhoid epidemic.

(*a*) *Observations.*—The Wilson 24-inch reflector has been in use on 34 nights. 29 plates have been secured, 11 being spectra, mostly of γ Cassiopeiæ. From September onwards the telescope was used for direct photography at the Newtonian focus. 4 plates were exposed on the super-nova in I.C. 4182 and 10 on the super-nova in N.G.C. 1003. The other plates are of special star fields taken for photometric purposes, such as the North Polar Sequence, the Pleiades and various test plates for other purposes.

The 8-inch Fry telescope was used on 47 nights, and sunspots were observed and measured on 10 occasions. The observations included 7 occultations observed by Mr. Frank Robbins, and photographs of the super-novæ and of different star fields for experimental purposes. In all, 25 plates were taken with Mr. Frank Robbins's astro-camera attached to this telescope.

(*b*) *Publications.*—At the November meeting of the Society a paper was read on the photographic light-curve of the second super-nova (145·1937 Persei), being based on 8 reflector-plates. Two other publications are nearly finished, the one dealing with the spectra in the earliest stage of Nova Herculis, the other with the 1937 eclipse of ζ Aurigæ. A considerable

part of the comprehensive series of α Andromedæ spectra, secured in the past years at Cambridge, has been measured for radial velocity with the object of obtaining a new spectroscopic orbit and of clearing up some of the interesting astrophysical problems offered by this star system. The investigation of the spectra of γ Cassiopeiæ has been continued. It is expected that these papers will appear in 1938.

(*c*) *Instruments.*—A Brunswiga calculating machine, 13 Z, has been purchased. Mr. C. Spratt built, in the Observatory workshop, several auxiliary pieces of apparatus such as an illumination arrangement for the measuring miscoscope. He has in hand a sensitometer to be used in connection with the ultra-violet spectrograph for work on line intensities. The spectrograph itself is under reconstruction in the workshop of the Solar Physics Observatory at Cambridge, thanks to a very kind offer from Professor Stratton. It is hoped that when the alterations are completed, spectrograms may be extended to fainter magnitudes.

(*d*) *The Radcliffe Telescope.*—During the spring the University authorised the Wilson Observer to superintend the building of a library and an observatory to house this telescope, and its re-erection, together with the dome and rising floor which were dismantled from Oxford. This occupied a considerable portion of his time. It is hoped that the work will be completed during the spring of 1938.

(*e*) *Staff.*—An addition to the staff, the need of which was pointed out in former annual reports, was made by the appointment on July 1 of Dr. Arthur Beer, of the Solar Physics Observatory, Cambridge, as First Assistant. Valuable assistance was given in the first months of the year by Mr. Frank Robbins, mainly on the observation of occultations and obtaining clock errors. Mr. Robbins ceased work at the Observatory at the end of May, and for the time being the occultation programme has been suspended. Mr. C. M. Chao has been working full time at the Observatory as a Research Student since October with a view to obtaining the M.Sc. degree by thesis. Mr. R. Pring has also made some observations with the Fry telescope.

(*f*) *Library.*—The Observatory has succeeded in increasing its library considerably, and has to acknowledge with many thanks numerous and valuable gifts. Professor F. J. M. Stratton and Dr. R. v. d. R. Woolley especially have taken an active interest in this matter. Further important gifts have been received from Sir Arthur Eddington, Dr. R. O. Redman, Mr. E. G. Williams, the Editors of the *Observatory*, Sir Richard Gregory, as Editor of *Nature*, etc. An arrangement with the two last-mentioned donors made it possible, in exchange for notes and reviews made by the Observatory staff, to keep the current journals nearly complete and up to date. The new library building adjoining the Radcliffe dome will be equipped during the spring.

(*g*) *Visitors.*—The number of visitors during the year was 78.

(*h*) *University College Observatory.*—The instructional work has been continued on the same lines as in previous years.

University Observatory, Oxford
(Director, Professor H. H. Plaskett, F.R.S.)

Staff.—Mr. T. L. Page has been appointed as Chief Assistant, and Miss M. G. Adam as Research Assistant, while Dr. H. Zanstra has commenced his duties as Radcliffe Travelling Fellow in Astronomy. Otherwise the staff remains unchanged.

Equipment.—As reported last year, Hartmann tests of the solar telescope revealed the presence of astigmatism with a path difference of $\lambda/2$. After some additional and confirmatory tests the three flats were returned to Grubb, Parsons; they found the two 16-inch flats to be satisfactory, but the 5-inch Coudé flat traversed by a cylindrical depression. As this depression had not been present on completion of the figuring, there seems little doubt that the fused quartz disc had changed shape in the interval. This disc was accordingly replaced by a new clear fused quartz one, and the latter figured by Grubb, Parsons during the summer to an accuracy of $\lambda/10$, as revealed by a subsequent test on a Hilger Interferometer. On the return of the three discs further Hartmann tests were made in October and December, and these somewhat surprisingly revealed the persistence of astigmatism with a new axis and a path difference of nearly a wave-length. From the tests by the makers this astigmatism presumably does not originate in the flats, nor does it originate in the $12\frac{1}{2}$-inch paraboloid, as is clearly shown by successive tests when this mirror is rotated. This leaves the convex Cassegrain as the only likely source, and it is now proposed to replace this mirror.

Due to delays in manufacture and to a necessary change in the design of the control system, the assembly and adjustment of the solar spectroscope is not yet complete. Work, however, is now going forward well, and the instrument should be ready for use in the spring.

Astrophysics.—In addition to work in connection with testing and installing the solar telescope and spectroscope, the director has continued his work on the surface brightness of the Sun as a function of wave-length and position on the disc. Filter transmission determinations are still in progress, and it will probably be some eighteen months before the first results are ready for publication. Miss Adam in the course of her study of the solar Swan bands, now nearly complete, has found that all faint lines, atomic as well as molecular, are strengthened at the limb (*M.N.*, **98**, 112), and has concluded that this strengthening arises from reduced re-emission in these faint lines. Mr. Page, after exhaustive trials of the arc spectra of the alkalis and alkaline earths at various pressures, succeeded during the year in getting good recombination spectra of hydrogen in the electrodeless discharge. Fully calibrated and standardized spectra of this source were obtained, and are now in course of measurement and reduction for a test of the Kramers-Gaunt absorption law. In collaboration with Mr. Bailey, Mr. Page has designed a small quartz objective prism spectroscope (at present mounted on the Astrographic Telescope) with which spectra of the Orion

Nebula have been obtained for the purpose of determining "Zanstra-temperatures" of the trapezium stars, and for an investigation of the strong visual continuous spectrum. Dr. Zanstra has commenced a theoretical study of problems of line formation and mechanical support of the solar chromosphere, and has already obtained a number of interesting results.

Astrographic Catalogue.—Work on the two Potsdam zones, $+32°$ and $+33°$ of the Astrographic Catalogue, has continued under the direction of Mr. H. Scott Barrett. Zone $+32°$ is now completely measured and the copy for press completed, except for two plates waiting revision. Zone $+33°$ is measured and the copy ready for press up to 17 hours; 16 plates have still to be measured to complete this zone. Recomputation of plate constants has been carried as far as 15 hours in both zones, and it is now anticipated that this programme will be completed early in 1939.

Norman Lockyer Observatory, Sidmouth
(*Director, Mr. D. L. Edwards*)

There were 108 fine nights during the year, on 106 of which successful observations were made with one or more instruments. The 12-inch McClean telescope was used for obtaining spectra of A-type stars, some short-period spectrum variables, Finsler's Comet and ζ Aurigæ during its recent eclipse. Some preliminary experimental work has also been done to test the possibility of undertaking colour-temperature work on early type stars with this instrument. This has involved some readjustments of the swing-back attachment to the telescope in order to get good definition in the $H\alpha$ and $H\gamma$ regions simultaneously, the taking of a number of focus plates, and testing various brands of panchromatic plates to find the one most suited to the purpose. The results appear to indicate that such work can be profitably taken up, and it is hoped that a regular programme of colour-temperature observations may be commenced at an early date. A total of 141 negatives were obtained with this instrument.

The 9-inch Kensington telescope has been used on a selected number of bright-line stars (with special attention to γ Cassiopeiæ, which continues to show interesting irregular changes), and of the brighter B-type stars in the near ultra violet. Occasional photographs of star fields have been taken with the attached Zeiss triplet camera, and the three meteor cameras fixed outside the dome have been used on some moonless nights, but no meteors have been recorded. The total number of negatives obtained was 75.

The Mond equatorial has been used for direct photographs of galactic clusters, the Andromeda nebula and Finsler's Comet. The last object was photographed on 12 different nights with each of the four cameras belonging to this instrument, and all the principal changes in the tail of the comet were well shown.

The negatives of Nova Lacertæ (1936) have been measured and discussed, and work continued on the classification and absolute magnitudes of B-type stars from objective prism spectra. Much preliminary work

has also been done in connection with the proposed colour-temperature investigation. The results obtained from the Nova Lacertæ spectra have been communicated to the Society.

Stonyhurst College Observatory
(Director, Rev. J. P. Rowland, S.J.)

The staff of the observatory remains unchanged, the only full-time assistant being Mr. W. Brown, whilst the Rev. H. Macklin, S.J., and the Rev. J. Lawrence, S.J., who are on the teaching staff of the College, render such assistance as their other duties permit.

The usual routine work of the observatory has been maintained throughout the year.

Drawings of the Sun have been made on all days when observation was possible, and these have been supplemented by copies of drawings made at Zürich, kindly supplied by Professor Brunner, to whom have been supplied copies of the Stonyhurst drawings on a number of days on which no observation was obtained at Zürich. Counts of groups and nuclei have been sent quarterly to Professor Brunner for the preparation of "Sunspot Numbers" and "Solar Character Figures," and "Daily Magnetic Character" numbers and "Declination Ranges" have been supplied to the International Organisation at De Bilt. Owing to the great increase in solar activity and the limitations of staff it has not yet been possible to complete the measurements of the solar drawings.

A few photographs of Comet Finsler were obtained when it was near its maximum brightness in 1937 August.

It may be noted that the current year, 1938, marks the centenary of the establishment of the observatory.

Dominion Observatory, Ottawa, Canada
(Dominion Astronomer, R. Meldrum Stewart)

Meridian Work and Time Service.—Work was continued on the regular programme with the meridian circle, and observations were obtained on 103 days. Observations with the reversible transit for clock corrections were secured on 77 nights. Instrumental constants were determined regularly and the necessary computations carried on. The standard sidereal clocks were compared twice daily and have maintained fairly uniform rates. Wireless time-signals were received regularly from Rugby, Annapolis, Bordeaux, Nauen, Monte Grande and Rio de Janeiro. The times of reception were sent monthly to the Bureau International de l'Heure. As in former years, time-signals were distributed from the Observatory by clock beats over the telephone and by short-wave radio signals. The time-signals were also given to the Canadian Broadcasting

Corporation for broadcasting over station CBO, and the beats of the Shortt clock were supplied continuously to the two radio monitoring laboratories. The synchronized time service to the various Government buildings has continued to give satisfactory service. The usual amount of repairing and rating of chronometers, watches and other small instruments was done.

Solar Physics.—The year was exceptionally cloudy and hazy, with low visibility. Solar photographs numbering 42, and 44 spectrograms, were obtained. Reduction of the observations of 1911, including remeasurements for the elimination of oil error in the micrometer, were completed, and much of the tabular material has been finished for publication. Similar work was continued on the large series of observations in 1914. All observations yield consistently lower values for the rate of the solar rotation than those derived before the commencement of the Ottawa series, the equatorial values being at least 5 per cent. lower.

Fifteen-inch Equatorial.—Observational work during the year was carried on with the spectrograph and the photo-electric photometer. Poor observing conditions prevailed, particularly during the latter part of the year. Microphotometer tracings were made from plates of Nova Lacertæ and a series made from spectra of different types, and some measurements made. A chart showing the position of Finsler's Comet with a descriptive note was prepared for distribution. As in former years the telescope was in use for public demonstration every clear Saturday, and popular descriptions of celestial objects were prepared quarterly in pamphlet form for distribution.

Meteor Observations.—Meteor observing was carried on in August, but weather conditions greatly reduced the possible hours of observation. One bright meteor was recorded photographically, and its position measured and computed.

Photographic Photometry.—Photographic observations were continued on the Cepheid fields, plates being obtained of UX Aurigæ, RZ Geminorum, RS Bootis, R Coronæ Borealis, RZ Cephei, VV Cassiopeiæ. Photometer measures were made on the fields of Nova Herculis, Nova Aquilæ, Y Aurigæ, RT Scuti, VX Cassiopeiæ, RZ Cephei, XY Cassiopeiæ, VY Cassiopeiæ and the Pleiades. Finsler's Comet was photographed in July and August. Measurements of the magnitude of ζ Aurigæ were attempted during the period of minimum light, but poor weather and the low altitude of the star made it impossible to secure observations.

David Dunlap Observatory, University of Toronto
(*Director, Professor R. K. Young*)

Spectrographic Work.—Observational work on the spectra of approximately 500 stars in and near the Kapteyn areas is nearing completion. During the year 1100 spectra were obtained and 1187 have been measured.

Work has been continued on the programme of eclipsing variables, but

owing to the desire to push the main programme of velocities not so much progress as last year has been made on these stars.

Thirty-three spectrograms of the planet Mars during the opposition of 1937 were secured by Dr. Millman. These are being used in a spectrophotometric study of the surface of the planet.

Dr. Heard has completed and published a preliminary orbit of the spectroscopic binary H.D. 96528. A preliminary orbit of H.D. 142926 has been completed. A study of the velocities from the absorption lines of Nova Lacertæ has been published. Dr. Heard has also continued the study of the variations in the spectrum of γ Cassiopeiæ.

Newtonian Focus.—Dr. H. S. Hogg in co-operation with F. S. Hogg has secured 80 direct photographs of clusters. Thirteen new plates of N.G.C. 6402 were obtained and the seventy known variables have been estimated on them. Eighteen periods of variables have now been determined in this cluster. This cluster is an exceedingly difficult object to work with, as even on the large-scale photographs of the 74-inch reflector the congestion is bad.

Six new variables have been discovered in the exceedingly faint cluster N.G.C. 6366, where no variables were known to exist.

Meteor Observation.—The photographic and visual observation of the major meteor showers was carried out by Dr. Millman as in other years. One meteor spectrum was photographed as a result of exposure times totalling 53 hours with the meteor spectrograph, and eight direct meteor photographs were secured in a total exposure time of 24 hours. Five of the above photographs were secured with the rotating shutter. Twelve direct meteor photographs were also secured at co-operating stations.

Publications.—During the year Vol. 1, No. 1, of the *Publications* of the Observatory appeared. Also numerous papers were published in the *Journal of the Royal Astronomical Society of Canada.*

Dominion Astrophysical Observatory, Victoria, B.C.
(*Director, Mr. W. E. Harper*)

The observing weather was 14 per cent. below the average. On 178 nights with 1070 hours observing 1005 spectrograms were secured. The nineteen-year average shows 202 nights, 1250 hours and 1335 plates. The general trend towards fewer plates each year is due to the increasing faintness of the stars investigated. Measurement of the plates for radial velocity has kept pace with observation, there being 1020 measured during the year.

Minor additions to the equipment have been made. A photometer using a cæsium-oxide photo-electric cell in conjunction with a valve amplifier has been constructed for colour work with the 72-inch telescope. A new aluminum-on-glass grating was secured from Professor R. W. Wood late in the year, and preliminary tests show its usefulness in the red region. The eyepiece used for visual observations at the Cassegrain focus has been

rebuilt, giving a more satisfactory field. An aluminizing apparatus to aluminize the secondary mirrors has been practically completed during the year.

Considerable time was spent by Mr. Harper in securing and measuring plates for the revision of elements of spectrographic binaries. The orbit of the eclipsing binary AR Aurigæ was published and, in collaboration with Mr. Blanchet, the orbits of the spectrographic binary HR 5472 were determined. This is a triple system with a close pair revolving about each other in a period of 101 days. The pair moves about another body in a period of the order of 3320 days. In collaboration with four other members of the staff, a full discussion of Nova Lacertæ 1936, based upon plates secured here, was prepared, and the publication is now about off the press. The radial velocities of 917 stars secured over a number of years were prepared for publication in June. These results and all other published results for Class A stars were put in catalogue form and used as the basis of a determination of the solar motion. The resulting velocity is 16·5 km./sec. towards the point $\alpha = 265°{\cdot}0$, $\delta = +24°{\cdot}5$. There is no correlation of the velocities with galactic latitude.

Dr. Pearce completed his spectrographic investigations of the eclipsing variables RZ Cassiopeiæ and TW Draconis. A comparison of the 1936 orbital elements of RZ Cassiopeiæ, determined from 46 observations outside of eclipse, with the 1912 elements indicates that the line of apsides is rotating in a period of $18{\cdot}3 \pm 1{\cdot}2$ years. The spectrographic results completely confirm the photometric prediction of Dugan. No changes in the other elements were detected. From 17 observations during principal minimum a well-determined rotation effect was observed, from which the absolute dimensions of the system were deduced. The secular increase in the period of TW Draconis was determined as $(415 \pm 009) \times 10^{-10}$ days per revolution. The orbital elements of the bright A6 component derived from 33 observations outside of eclipse clearly indicate that no observable changes have occurred during the past 18 years. Three observations of the 10th magnitude class G5 companion during totality give an approximate value of the mass ratio of 0·28. Seventeen observations secured during the deep primary eclipse give a well-determined rotation effect from which the absolute elements of the system were derived.

The Greenwich list of colour temperatures was used by Dr. C. S. Beals as the basis for a series of photo-electric colour determinations using a cæsium-oxide photo-electric cell in conjunction with a valve amplifier. The results of this study indicated considerable promise for the method, but the demands of the spectrographic programme have so far prevented the extension of the work to fainter stars. Work has continued on the study of P Cygni type spectra. The intensity relationships between emission and absorption observed in P Cygni have been shown to hold for other stars of similar type. What are believed to be transition types between P Cygni and Be stars have been observed, and evidence has been adduced that the P Cygni type spectrum is not invariably associated with high luminosity. With the aid of an aluminum-on-glass grating, previously referred to, the interstellar

sodium lines of the stars ζ Orionis, ϵ Orionis and ρ Leonis have been shown to be complex, exhibiting structure similar to that of the corresponding *Ca*II lines of the same stars. A study of the intensities of the interstellar lines in these stars has provided conclusive evidence that the intensity ratio *Na*/*Ca*II is not constant for different regions of the sky.

Dr. R. M. Petrie has continued spectrographic observations of 18 bright spectrographic binaries. High dispersion was used in the majority of cases and the observing will be completed during 1938. The orbits of the components of HD 109510 have been completed and are in process of publication. A long-continued study of the star HD 199140 is approaching completion. Results obtained to date show that it is a β Cephei star in which the radial velocities, spectral type and spectral line profiles vary in a period of approximately five hours. Further observations during 1938 will complete this phase of the study. The determination of line profiles in double-line spectroscopic binaries is proceeding. The study of the bright objects of this class is expected to reach completion this year. A study of the rotation effect in eclipsing binaries has resulted in a formula for computing this quantity without recourse to graphical methods.

The study of the profiles of emission bands in the spectrum of Nova Lacertæ 1936 was completed by Dr. A. McKellar. Results of this investigation indicated that the photo-electric temperature of Nova Lacertæ was about 65,000° K, increasing somewhat with time, and that the Balmer decrement for the hydrogen emission bands corresponded fairly well with those found for gaseous nebulæ and Be stars. An investigation was made of the spectra of the supernovæ in the systems I.C. 4182 and N.G.C. 1003, of which spectrograms were obtained at this observatory with the relatively high dispersion of 92 angstroms per millimetre at Hγ. It was not found possible to identify the broad emission bands, or any of the spectral features occurring, with those of normal novæ spectra or with any known radiations. A number of the bands, having widths corresponding to several thousand km./sec., were found to be complex in structure. Additional spectrograms of faint R- and N-type stars were secured for the investigation of the C_2 Swan bands. Computational work was carried on in connection with the study of the isotope effect in the red bands of Li_2. The orbit of the spectrographic binary star HD 214652 was determined and the results published. Orbits for the binaries HD 195986, HD 207826 and HD 110533 are near completion, no more observations being required in the cases of the first two of these stars.

Mr. K. O. Wright has continued the study of the central intensities and equivalent widths of 150 lines in the spectra of Sun and Moon, α Persei, γ Cygni and α Canis Minoris. These spectra have a dispersion at Hγ of 8 angstroms per millimetre.

During the year Nos. 17 to 22 inclusive of vol. vi of the *Publications D.A.O.* were put through the press. Nos. 1 and 2 of vol. vii are in press. A leaflet describing the observatory and the work carried on was issued for the benefit of our numerous visitors. Twenty-five technical papers were prepared for various scientific meetings during the year.

Helwan Observatory, Ministry of Public Works, Egypt
(Director, Dr. M. R. Madwar)

Time-Service.—The time-service was maintained as usual, the error of the standard Shortt clock No. 1 being determined from star transits. Rhythmic W/T signals were received daily from Bordeaux and Rugby during the morning, and the times of the first and last signals were determined by the aural method of coincidence (*H.O.B.*, No. 28).

The standard clock ran satisfactorily throughout the year, the range in the rate being $0^{s}\cdot33$ per day, and the range in the temperature of the clock room being $25^{\circ}\cdot4$ C.

The reversible transit-circle has been in use, and 28 transits were taken throughout the year.

Reynolds Reflector.—The reflector was used on a few nights only for trial plates with the newly fitted Ross correcting lens.

Nizamiah Observatory, Hyderabad
(Director, Mr. T. P. Bhaskaran, M.A.)

The work of the Observatory was continued generally on the same lines as in previous years. With the astrographic telescope 104 plates were taken in the regions of the Hyderabad Astrographic Zones for the determination of proper motions, besides 5 plates exposed on ζ Aurigæ in April.

The blink comparator was in regular use for the comparison of the plates of the new series with those originally obtained about twenty years ago for purposes of the *Astrographic Catalogue*. Fifty-five areas were compared with the instrument during the year.

Vol. viii, part 1, of the Hyderabad *Astrographic Catalogue* has been published and copies have been distributed. This part deals with the residuals of the reference stars taken from the *Catalogue de* 9997 *Étoiles* of the Algiers Observatory. Proofs of vol. xi (Zone $+37^{\circ}$) have been compared as far as R.A. 19^{h}, and the volume is expected shortly to be ready for publication. The MS. of vol. xii, containing measures of star images in Zone $+36^{\circ}$, has also been prepared, ready for the printer.

Good progress has been maintained with the reductions of the Eros photographs; the provisional places of the reference stars have been used in the reductions. The results will be revised on the basis of the definitive catalogues of positions recently published.

With the Grubb equatorial, regular observations of variable stars of long period have been continued and 1051 visual estimates of brightness were made during the year.

Forty occultations of stars by the Moon were observed (disappearances 32 and reappearances 8).

Observations with the transit instrument have been taken occasionally for the determination of clock corrections.

Kodaikanal Observatory
(Director, A. L. Narayan, M.A., D.Sc., F.Inst.P.)

Dr. T. Royds, who was connected with this Observatory for over twenty-five years and was its Director from 1923 to the beginning of this year, went on leave preparatory to retirement with effect from 1937 March 12, and Dr. A. L. Narayan succeeded him as Director. Dr. A. K. Das was appointed Assistant Director with effect from 1937 September 23.

The routine work of the Observatory has been continued as in previous years. Photoheliograms were obtained on 330 days, calcium flocculi plates on 317 days and *Hα* flocculi plates on 294 days. One calcium flocculi plate for each day was sent to the Solar Physics Observatory, Cambridge, as in former years.

Under the auspices of the International Astronomical Union, *K* prominence and *Hα* disc spectroheliograms were collected from other observatories whenever complete observations were not possible at Kodaikanal. The statistical data regarding prominences seen at the limb and by absorption on the disc are published in half-yearly bulletins.

Daily character figures of solar activity according to *Hα* bright flocculi and *Hα* dark markings have been communicated to the Observatoire Fédéral, Zürich, for publication as in previous years. Daily character figures as derived from calcium flocculi from Kodaikanal photographs are published by the Solar Physics Observatory, Cambridge.

Observations with the Hale Spectrohelioscope were made on all days of favourable weather except Sundays and holidays, special attention being given to bright chromospheric eruptions. A list of these bright eruptions observed together with the times of observations was sent quarterly to the Meudon Observatory, Paris, for inclusion in the bulletin of character figures published by the International Astronomical Union.

Several solar phenomena such as sunspots, bright chromospheric eruptions associated with these and prominences, visible in *Hα*, *H* and *K*, have been of frequent occurrence in the active zones. The general conclusion that can be drawn from the results of the routine observations is that all forms of solar activity have shown a slight increase during the year under review.

The results of the eclipse expedition to Japan were published in a paper by Dr. Royds in the *Monthly Notices of the Royal Astronomical Society*, **97**, 692, 1937. A study of the progressive change in the inclination of hydrogen dark markings to the Sun's meridian made by Dr. Royds and Mr. Md. Salaruddin was embodied in Kodaikanal Observatory Bulletin, No. CXI, published in 1937 February.

A note on the presence of oxygen in solar prominences by Drs. T. Royds and A. L. Narayan was published in *Current Science*, **4**, 734, 1937, Bangalore.

A systematic study of the contours of selected lines in different parts of the Sun's disc and particularly in sunspots has been undertaken by the Director and Assistant Director. A 13-foot prismatic spectrograph of

the Littrow type has been constructed for the purpose. Arrangements are in progress for the simultaneous measurement of the magnetic field and the temperature in sunspots.

With a view to making photometric measures of prominences and bright $H\alpha$ eruptions, an improved method of estimating intensities, using a step wedge, is being designed.

Union Observatory, Johannesburg
(Union Astronomer, Dr. H. E. Wood)

$26\frac{1}{2}$-*Inch Grubb Visual Refractor.*—3617 visual micrometrical measures of double stars were made during the year ; 8 photographic plates of double stars were taken.

Occultations of Stars by the Moon.—No change was made in the regular programme of observation of occultations of stars by the Moon ; 182 occultations were observed during the year.

The results of the year's observations are given below, the second column indicating the time by which the Moon has arrived too early at any longitude, and the third column the amount by which the Moon is ahead of its tabular longitude.

		s	"
	1937·14	5·5	3·0
	·36	6·1	3·4
	·62	4·3	2·4
	·82	3·8	2·2
Mean for year	·52	5·0	2·8

These results are, as in former reports, deduced from disappearances at the dark limb only. In obtaining the means, each occultation is given a weight equivalent to cos $(\chi - \rho)$, and no occultation is included for which the value of cos $(\chi - \rho)$ is less than 0·5.

Franklin-Adams Star Camera.—During the year 1202 plates were taken with this instrument. The distribution of the plates was as follows :—

Variable star regions	757 plates.
Minor planet regions	368 ,,
Comet regions	77 ,,

Comet 1937 *b* (Whipple) was observed from August 29 to October 28 ; Comet 1937 *f* (Finsler) from August 29 to September 23 ; and Comet 1937 *g* (Hubble) from August 6 to September 10.

62 new minor planets were discovered during the year, and elliptic orbits were computed for 10 new minor planets. 600 approximate positions and 108 accurately measured positions of minor planets were forwarded to the Astronomisches Rechen-Institut.

Union Observatory Circulars.—Circular No. 97 was published and distributed during the year. Circular No. 98 is in the press.

Miscellaneous.—The Transit of Mercury on May 11 was observed under fairly good conditions.

Dr. A. de Sitter of the Leiden Observatory arrived at the Observatory on April 21 to replace Dr. H. van Gent, who has returned to Leiden for a period.

The number of visitors to the Observatory during the year was 1386.

Radcliffe Observatory, Pretoria
(*Director, Dr. Knox-Shaw, Radcliffe Observer*)

Another milestone has been passed in the long journey from Oxford to Pretoria which began in 1929, for this year has seen the erection of office block and residences, and the virtual completion of the brick and concrete base for the turret. The steel turret and the mechanical parts of the 74-inch reflector are due to be shipped from England in January, and should be erected by the middle of the year, but it will be a long time yet before the telescope is in use, for the Corning Glass Co. has failed for the second time to cast a satisfactory disc of Pyrex glass for the large mirror. It is hoped that the third disc, which is now being annealed, will be ready for shipping to England in March. It can hardly be expected, however, that the finished mirror will arrive in Pretoria much before the middle of 1939. It had been hoped that it would be possible to have the mirror aluminized, but the cost has been found to be prohibitive, there being no facilities in England for dealing with such a large disc, and the observatory will have to be content with a silvered mirror.

The Director and Mr. E. G. Williams took up residence at the end of October. Dr. R. O. Redman is remaining in England for the present to test the telescope before shipment and to superintend the construction of spectrograph, microphotometer, measuring machines and other subsidiary apparatus.

Adelaide Observatory
(*Director, Mr. G. F. Dodwell, B.A., Government Astronomer*)

The routine work of the Observatory has been continued as in previous years.

1531 pairs of latitude stars were observed on 155 nights by Messrs. A. E. Markey and R. V. Burton. The results were sent to Professor L. Carnera at Naples, Director of the Central Bureau of the International Latitude Service.

A study of Ancient and Medieval observations of the obliquity of the Ecliptic has been continued, particularly observations of the Arabs and the ancient Chinese.

Commonwealth Solar Observatory, Canberra, Australia
(*Officer-in-Charge, Mr. W. B. Rimmer*)

Sun Telescope.—The determination of the water-vapour content of the atmosphere in the path of the Sun's rays at, or near, apparent noon of each day by comparison of the intensities of water-vapour lines in the yellow region of the Fraunhofer spectrum with adjacent solar lines has been continued.

For the purposes of calibration the same lines have been measured for a horizontal air-path of 1680 metres in which the amount of water-vapour can be derived. The calibration constant so far obtained by this method is in good agreement with that obtained with the infra-red spectrograph as described in last year's report.

Further photometry of the Fraunhofer spectrum is being carried out, using a step slit. Plates are being obtained to extend the observations to 3950 A., the limit in the violet for accurate photometry with the solar spectrograph.

The spectra of solar eruptions also are being obtained and studied.

Farnham Telescope.—Since 1937 January 28 this 6-inch refractor has been fitted with a camera for obtaining direct photographs of the solar disc 6 inches in diameter, in connection with the daily determination of the positions and areas of sunspots, etc.

The Hale Spectrohelioscope.—Routine observations of the solar disc have been made daily as outlined in last year's report. Particular attention has been given to bright hydrogen eruptions and the disturbances in the ionosphere which invariably accompany them. In collaboration with the Radio Research Board of the Council for Scientific and Industrial Research, a new type of ionospheric disturbance was discovered in addition to the usual radio "fade-outs." A theory has been put forward in which both these phenomena are attributed to the emission of the Lyman resonance line L_α (1215·6 A.) of hydrogen (see *Nature*, **140**, 603, 1937).

In connection with the spectrohelioscope reports an innovation has been introduced. The correspondence between ionospheric conditions and major bright hydrogen eruptions is so good that the records of ionospheric conditions (obtained by automatic radio methods) are being used to supplement the visual spectrohelioscope observations. Even on cloudy days the occurrence of major eruptions can be reported, and also the approximate time of the commencement of an eruption when only intermittent visual observations are possible.

During the latter part of the year the spectrohelioscope has been convertible into a spectroheliograph, from which records may be obtained at either 6- or 3-minute intervals according to solar activity. The 18-foot focus lens may be replaced by one of 6 feet focal length, giving a solar image of 17 mm. diameter. A Zeiss Ica camera is mounted on a frame which can readily be swung aside when visual observations require to be made. The instrument can be adapted for visual use, a survey of the disc made, and the spectroheliograph brought again into operation within three minutes.

Publications.—Publications during the year include three papers in *Gerlands Beiträge zur Geophysik*, **50**, pt. 2/4, 1937, viz. "Comparison of Two Abbot Silver Disc Pyrheliometers," pp. 385–387; "The Depletion of Solar Radiation by Volcanic Dust," pp. 388–393; "Measurements of Solar Ultra-violet Radiation with the Cadmium Photo-electric Cell," pp. 394–402.

General.—The programme of work, as outlined in reports of previous years, has been continued.

Melbourne Observatory
(*J. M. Baldwin, M.A., D.Sc., F.Inst.P., Government Astronomer*)

As in past years, the 8-inch transit-circle has been devoted to the observation of the Provisional General List of Fundamental Stars and to the determination of clock error, 2420 observations in R.A. and 1512 in Dec. being obtained. The staff has been mainly occupied in the reduction of these observations, but some time has been given to the further revision of the catalogue Me 5.

With the 8-inch equatorial, 2342 observations of long-period variables have been made, and the results have been sent each month to the Harvard College Observatory for publication in *Harvard Annals* with those of other members of the American Association of Variable Star Observers. This is the largest number secured here in one year. In addition, this telescope has been used for observation of occultations listed for Melbourne in the *Nautical Almanac*. The observations up to August 15 have been reduced. The reduction of the remainder will be put in hand shortly, and the results forwarded to the *Nautical Almanac* Office.

No advance has been made in publication of the fourth and fifth *Melbourne General Catalogues* or of vols. 4 and 5 of the *Astrographic Catalogue*, as no money has been granted for this work. The only work that has been possible on the *Astrographic Catalogue* has been the computation of final plate constants, which is now complete, except for nine plates not yet reduced, up to $-77°$, $17^h\ 15^m$, and some revision of vol. 4 of the Catalogue.

A second Shortt Free Pendulum Clock was purchased during the year, and has been erected in the clock vault.

Riverview College Observatory, N.S.W.
(*Director, Rev. W. O'Leary, S.J.*)

Through the courtesy of the Surveyor General of New South Wales, Mr. H. B. Mathews, a survey was carried out by Mr. Surveyor Della Ca connecting Riverview Observatory with the Trigonometrical Survey of N.S.W. The position thus obtained for the principal equatorial is :

Latitude $-33°\ 49'\ 45''{\cdot}7$.
Longitude $10^h\ 04^m\ 37^s{\cdot}99$ E.

This position is based on that of Sydney Observatory, which is the origin of the Trigonometrical Survey.

984 plates were taken up to the end of November, mostly in connection with the variable star programme. A few comet photographs were taken.

The publication in the *Nautical Almanac* of occultation predictions for Sydney is a welcome innovation, as the time previously spent here in working out predictions could ill be spared. The weather during the year was

rather better than the average of recent years, and nearly half of the possible *Nautical Almanac* occultations were observed.

The free pendulum of the O'Leary free pendulum clock has been transferred to a more suitable underground chamber, where temperature changes are small. It is hoped that a regular thermostatic control will be installed before long.

Publications.—Riverview *Publication*, No. 3 (D. O'Connell, S.J.: "Photographic Light Curves and Orbits of Eclipsing Binaries"), and Reprint No. 1 (D. O'Connell: "Easter Cycles in the Early Irish Church") have been distributed. Papers on AR Puppis by the Director and on W Serpentis by D. O'Connell have been published in vol. viii of the *Annals* of the Bosscha Observatory, Lembang. Further papers on variable stars will appear shortly in Riverview and Lembang publications. A list of new variable stars, with provisional elements, was published in the *Astronomische Nachrichten.* A considerable number of other new variables has been discovered with the blink comparator, but their publication is deferred until further work has been done on them.

Dominion Observatory, Wellington, New Zealand

(Report for the Years 1936–1937)

Acting-Director, Mr. R. C. Hayes

Time Service.—This Observatory controls the time service for the whole of New Zealand. Time-signals have been sent out as in previous years, with the exception of the following two alterations :—

(1) The radio time-signals sent out on Tuesday and Friday evenings on 600 metres were discontinued after 1936 June 30.

(2) The lights extinguished at 9^h, U.T., as a visual time-signal at Wellington and Auckland, were discontinued after 1937 October 31.

Solar Work.—Observations of sunspots have been made at Wellington with the 5-inch refractor of the Wellington Philosophical Society's Observatory. This work is carried on under the direction of Mr. I. L. Thomsen. Results of the observations are sent to Zürich, and reports are published by the Solar Section of the New Zealand Astronomical Society. Reports of particularly active groups are supplied to the local press. Solar observations have also been made in Southland by Mr. M. Geddes, using the 5-inch refractor on loan from this Observatory.

Occultations.—Observations of occultations of stars by the Moon have been carried out by officers of the Observatory in co-operation with the Wellington City Observatory, the New Zealand Astronomical Society, and the New Plymouth Astronomical Society. During the years 1936 and 1937 conditions were not very good for this work, and consequently the number of observations was less than in previous years. Observations are reported to the *Nautical Almanac* Office and to the Computing Section of the British Astronomical Association.

Longitude Work.—The work of reducing the observations for longitude

carried out in 1933 October–November has been completed. A copy of the detailed results was sent to the Bureau des Longitudes, and a summary of the results was published locally, and issued as a bulletin of this Observatory. The mean results of the transit observations gave the longitude of the transit pier as $11^h\ 39^m\ 3^s{\cdot}97$ East of Greenwich ; and this value has been adopted until further determinations are made.

Aurora Work.—Observations of the aurora australis have been carried out under the direction of Mr. M. Geddes, Director of the Aurora and Zodiacal Light Section of the New Zealand Astronomical Society. On account of the favourable locality of southern New Zealand for observing the auroræ, efforts have been made recently to increase the facilities for carrying out this work. Two observing stations are now established, each equipped with a special aurora camera ; and although communication has proved somewhat difficult, a large number of successful photographs of auroræ has been obtained, including several simultaneous sets which will be available for the determination of heights. Steps are being taken to improve the means of communication between the two observing stations so that a greater number of simultaneous sets can be obtained. Observations of auroræ are reported to Professor Störmer, Norway, and reports are published in the *Journal of the New Zealand Astronomical Society*.

Solar Eclipse of 1936 *December* 14.—The expedition organised by Mr. C. W. B. Michie to observe the annular eclipse of the Sun on 1936 December 14 included Mr. I. L. Thomsen of this Observatory as official representative. The expedition was located at Pukekohe in the North Island and, although much trouble was experienced from clouds, sufficient data for useful results were obtained. A small semi-official party was also located at Tauranga, about 70 miles south-east of Pukekohe, where observations were made under favourable conditions. Good observations of the partial phase of the eclipse were obtained at Wellington and other places. A feature of this eclipse was the large fall of temperature observed, even at places outside the central zone. At Wellington a fall of 4·9° C. was attributed to the eclipse. Results of the observations of this eclipse are being published in the *Journal of the New Zealand Astronomical Society*.

Total Solar Eclipse of 1937 *June* 8.—The expedition organised and led by Mr. C. W. B. Michie to observe the total solar eclipse of 1937 June 8 at Canton Island included Mr. I. L. Thomsen of this Observatory, who acted as Government Astronomer at the eclipse. Arrangements were also made by the Department of Scientific and Industrial Research for Mr. M. Geddes to be a member of the expedition. The expedition left Auckland by mail steamer for Suva on May 14, and was conveyed thence to Canton Island in one of His Majesty's ships. Twelve days were spent on the island in preparation for the eclipse, which was observed under favourable conditions. After the eclipse, the expedition returned to New Zealand by way of Samoa. The results of this eclipse appear to be very satisfactory. Preliminary reports have already been published in the *Journal of the New Zealand Astronomical Society* and elsewhere, while more detailed reports are in course of preparation.

Miscellaneous Astronomical Work.—Other astronomical work of special importance includes :—

(1) Observations of Saturn during the disappearance of the Rings in 1936 June, by I. L. Thomsen.

(2) Some early observations of Comet Peltier by Thomsen and Hayes in Wellington, and by Geddes in Southland ; made in 1936 August.

(3) An Ephemeris of Comet Finsler computed by I. L. Thomsen in 1937 July.

Other astronomical observations have been carried out from time to time, reports of which have been published in the *Journal of the New Zealand Astronomical Society.*

This Observatory co-operates with the New Zealand Astronomical Society in directing astronomical research work in New Zealand.

Publications.—During the years 1936 and 1937 the following astronomical bulletins were distributed to the principal astronomical observatories and institutions throughout the world :—

Bulletin 96—Mean Time and Time Service.
,, 105—Report of the Dominion Astronomer and Seismologist for the year 1934.
,, 112—Annual Report of the Dominion Observatory for the year 1935.
,, 115—International Longitude Determinations, 1933 October–November (R. C. Hayes and I. L. Thomsen).
,, 118—Observations during the Disappearance of the Rings of Saturn, 1936 June (I. L. Thomsen).
,, 120—The Position of New Zealand Auroræ (M. Geddes).
,, 125—Annual Report of the Dominion Observatory for the year 1936.

Mr. Robert Barker's Observatory, Cheshunt, Herts

Although only 19 observations of Mars were recorded, a chart of the planet at all longitudes was obtained. Lunar work resulted in the addition of several clefts and formations to the map.

The occultation of Mars was seen, and an occultation of Titan (by Saturn) was followed.

The shadows of Dione and Tethys were seen in transit across Saturn.

A streak of orange-yellow was plainly observed on the west wall of the lunar formation Plato. Later observations under a higher sun showed a considerable extension of this coloured streak. This was the worst year for telescopic observations experienced at Cheshunt.

Mr. Evershed's Observatory, Ewhurst, near Guildford

Spectroheliograms in $H\alpha$ light for the estimation of character figures were obtained on 104 days during the year. The general activity shown by these plates was greatest in February and August, the character figure 5

being recorded on February 1 and 20 and August 17. The results have been communicated to Dr. Brunner.

Prominence photographs were secured on 63 days, and bright hydrogen eruptions on the disc were recorded on 11 days.

Prominence spectra near the east and west limbs have been obtained with the spectroheliograph used as a spectrograph, for estimating rotation speeds and shift of the H and K lines compared with the arc lines of calcium.

The liquid prism spectrograph has been employed in photographing the D lines of sodium at the centre of the Sun and at various points on the limb with a comparison spectrum produced by a Philips low-pressure sodium lamp. The results of measures of 100 spectra show that the general shift towards red of the line D1 agrees very closely with the theoretical relativity shift, and, unlike the lines of iron, the shift is no greater at the limb than at the centre of the disc. The line D2 cannot be measured accurately owing to a water-vapour line interfering on the red edge.

Mr. F. J. Hargreaves's Observatory, Kingswood, Surrey

The work of this observatory during the past year has consisted of visual observations of Mars, Jupiter and Saturn. The comparison-image micrometer described in *M.N.*, **92**, 1 and 5, is being re-installed, and measurements of double stars will shortly be resumed.

Dr. J. L. Haughton's Observatory, Teddington

The work on lunar occultations has been continued. Owing to the bad weather during the first half of the year only ten were observed.

More photographs in the nova search series, and a number of photographs of Comet 1937 *f*, were taken.

An 8-inch mirror has been purchased, and it is hoped to build the tube, etc., and mount the instrument during the coming year.

Mr. M. B. B. Heath's Observatory, Kingsteignton, Devon

Observations of the physical features of Mars and Mercury were made, but owing to cloudy skies those of the latter planet were much fewer than in the previous year. All records were sent to the British Astronomical Association.

Mr. F. M. Holborn's Observatory, Streatham, London

Observations were made on 134 nights during the year. Eleven visual estimates of brightness of Nova Herculis were made, and 24 of Nova Lacertæ.

1626 observations were made of 63 variable stars. A few observations

were made of Saturn for visibility of the rings near the time of minimum opening.

Between May 1 and December 31 the Sun was observed on 147 days, on 109 of which naked-eye spots were seen.

All records were sent to the British Astronomical Association. The observatory was moved in March to :

Long. $+0^h\ 0^m\ 33^s{\cdot}04$.
Lat. $+51^\circ\ 25'\ 33''{\cdot}1$.
Altitude 38 metres.

Mr. A. M. Newbegin's Observatory, Worthing, Sussex

So far as adverse weather and ill-health permitted, the usual routine work on prominences and sunspots has been maintained with the $6\frac{1}{4}$-inch telescope, but much more time has been given to observations with the spectrohelioscope.

During the year sixty bright chromospheric eruptions were recorded and details sent to Meudon for inclusion in the tables published under the auspices of the International Astronomical Union. The majority of these eruptions, which were observed in the $H\alpha$ line, were of intensity 1, and very few were recorded of intensity 3.

Measurements of radial velocities in dark flocculi connected with sunspots were made whenever possible, but very few violent eruptions were seen.

Motions in eruptive prominences, interpreted as radial velocities, were observed on a number of days. The most noteworthy eruptive outburst occurred on November 5 in lat. $+10^\circ$, seen in conjunction with a bright chromospheric eruption within 5° of the west limb of the Sun. Radial velocities of increasing speed were noted, culminating with a maximum velocity of +166 km./sec. Both the prominence and the bright eruption on the disc were of short duration, and both terminated almost as suddenly as they began.

The 9-inch Coudé has been out of use for the greater part of the year, Mr. Bernard Pitcher being away at the University of Bristol engaged on geological research work.

Mr. B. M. Peek's Observatory, Solihull, Birmingham

Physical observations of Jupiter suffered considerably in 1937 from the low declination of the planet, but as much work as possible was accomplished on the usual lines.

Photometric observations of Nova Persei 1901, U Geminorum and SS Aurigæ have been continued, while Nova Herculis 1934 has been kept under intermittent observation.

Owing to the prevalence of cloud, only 7 occultations of stars by the Moon were recorded during the year.

A considerable amount of time has been spent on the reduction of Jupiter

observations made by members of the British Astronomical Association, Jupiter Section, during the years 1931–34; the results of these will be incorporated in forthcoming *Memoirs* of the Association.

The Rev. T. E. R. Phillips's Observatory, Headley, near Epsom

The systematic observation of Jupiter has been continued, the number of spot transits recorded being rather over 500.

Observations of Saturn have also been obtained. The N. belt, which was at first very dark and well defined, faded greatly as the apparition advanced, but, apart from the interesting changes in the appearance of the ring-system and its shadow with the relative variations in the elevation of Earth and Sun above its plane, there was little else of importance to record. No definite spots or irregularities on the globe were observed at Headley, and overcast skies or bad seeing hindered the observation of the predicted satellite phenomena.

Systematic observations of Mars and its surface features were made so far as the planet's poor position permitted, and the occultation of Mars (disappearance) on July 17 was observed under good conditions of seeing.

The measurement of double stars with the 8-inch refractor lent by the Society has been continued and a list of the measures since 1934 was published in *M.N.*, **98**, 88 *et seq.*

Owing to illness, absence from home, and other causes, Dr. R. L. Waterfield has been unable to continue his work with the 6-inch Cooke triplet.

Mr. F. J. Sellers's Observatory, Muswell Hill, London

The Sun was observed on 218 days during the year and quarterly reports of observations were published in the *B.A.A. Journal.* These show that, except for a drop in March, the mean daily frequency of spots and prominences has remained fairly consistent, near maximum, until the middle of October. Peaks were reached about January–February and July–August, but in November and December there was a considerable falling off in activity.

The spectrohelioscope has been in daily use whenever observing conditions allowed. Fifteen bright hydrogen eruptions have been observed, recorded and reported, notably on April 25, August 2, 12 and 30, and October 1, 4 and 24.

Dr. W. H. Steavenson's Observatory, West Norwood

Observations were made on 122 nights during the year.

The 20½-inch Hindle reflector was, as usual, employed chiefly for the observation of comets and faint novæ.

Comets Whipple, Wilk-Peltier and Finsler were observed for position on 44 nights, and the measures have been communicated to the Society.

228 photometric observations of 15 faint novæ were made during the year, and some of the results have been communicated to the Society.

A $5\frac{1}{2}$-inch Cooke refractor, on altazimuth mount, presented by the Rev. R. H. Consterdine, has been added to the equipment of the Observatory. It has been found useful for the observation of objects so situated as to be temporarily or permanently inaccessible to the reflector. The mirrors of the latter were resilvered in October.

Wolsingham Observatory (*Rev. T. E. Espin's*), *Tow Law, Co. Durham* (*Observer, Mr. W. Milburn*)

The mirrors of the large reflector were resilvered here in the summer and the new shutter was successfully installed. It works very satisfactorily.

The usual programme of remeasurement of certain known double stars, chiefly those discovered at this observatory, has been continued with the 24-inch Calver reflector, together with the survey for new double stars in the unexamined parts of the B.D. zones $+35°$ to $+40°$. The results have been communicated to the Society.

REPORTS ON THE PROGRESS OF ASTRONOMY

ABSORPTION OF LIGHT IN SPACE

The recent greatly increased interest taken by astronomers in problems of interstellar absorption has led to a rapid collection of new data which promise, in the course of time, to yield much knowledge about the amount and constitution of matter in interstellar space. The most direct knowledge is obtained from observations of wave-lengths and intensities of interstellar absorption lines. The following report, however, will only be concerned with such knowledge as can be obtained from observations of general or only moderately selective absorption in space.

The problem divides itself naturally into three sections:

1. The density distribution of absorbing matter in space. 2. The study of the absorption coefficient as a function of wave-length. 3. The physical and chemical constitution of the particles producing the interstellar absorption.

Distribution of Absorbing Matter.—Information about the distribution of interstellar matter may be obtained from an analysis of the apparent magnitudes of stars with known absolute magnitudes and distances. Let the optical thickness of the layer of absorbing matter interposed between the observer and a given star be denoted by τ, for a definite given wave-length, and let m and M denote the apparent and absolute magnitudes of the star and r its distance in parsecs. If no absorption were present, the apparent luminosity of the star, $K \cdot 10^{-0{\cdot}4 \cdot m}$, would equal $\left(\frac{r}{10}\right)^{-2} K \cdot 10^{-0{\cdot}4 \cdot M}$. When absorption is present the latter quantity must be multiplied by $e^{-\tau}$, and the consequent relation between m, M, r and τ becomes

$$M = m + 5 - 5 \log r - 1{\cdot}09 \cdot \tau. \qquad (1)$$

Denoting the absorption coefficient for the given frequency by κ, we have

$$\kappa = \frac{\partial \tau}{\partial r}. \qquad (2)$$

Provided a sufficiently large material of stars with known values of m, M and r were at hand, it would clearly be possible by means of (1) and (2) to derive the form of κ as a function of the space co-ordinates and the frequency of the incident light.

The difficulties encountered in carrying through this programme consist essentially in lack of accurate data concerning M and r, though sometimes the lack of accurate data concerning apparent magnitudes and colour equivalents are just as serious.

Although several important papers concerning interstellar absorption have appeared earlier, we shall here only be concerned with papers from the last decade, since this work has superseded earlier work on all points. It may be fair to begin with a paper by Schalén in 1929 (*A.N.*, **236**, 249, 1929), which brought out the importance of interstellar absorption very clearly. Schalén wanted to find out whether the apparent thinning out of the star density with increasing distance from the Sun, which was demanded by all previous star counts, might not be a spurious effect, due to the neglect of a possible interstellar absorption in the analysis of the star counts. Some variations in star density might of course be expected in directions towards or away from the galactic centre, but a falling off of star density in a direction at a right angle to this axis seemed surprising. Schalén therefore analysed the star counts in the Cepheus-Cassiopeia region, and found that an absorption of about $0^m.5$ magnitudes per kiloparsec would remove the observed negative density gradients for this direction. The natural inference from this investigation would seem to be that the local system does not exist at all. But, according to a subsequent investigation by Bok (*Harvard Circ.* 371, 1931), this inference would be premature. Bok found that it was not possible to remove a negative density gradient for all directions by assuming a layer of constant absorption to exist in the solar neighbourhood. On the contrary, if the star density is supposed to be uniform, it is necessary to postulate a non-uniform distribution of absorbing material, which again is spherically symmetrical round the Sun—just the feature the assumption of an absorbing layer was introduced to avoid. Bok concluded that an absorption of $0^m.4$ per kiloparsec would give the best representation of his material. The resulting form found for the local system showed a distinct elongation in the direction of galactic rotation, which, perhaps, may be considered as a favourable point. (See further Schalén, *Nova Acta Regiæ Ups.*, Ser. 4, vol. 8, fasc. 1, p. 63, 1932.)

More definite data concerning the distribution of absorbing matter in space was obtained from an investigation by Trumpler (*L.O.B.*, **14**, 154, 1930) of the structure of open galactic clusters. Trumpler was engaged in an extensive investigation of 334 clusters, distributed along the Milky Way. The absolute magnitudes of the stars were obtained from a spectral classification of the cluster stars in a Hertzsprung-Russell diagram. The distances, on the other hand, were obtained from a classification of the clusters themselves according to population, central condensation, etc., on assuming that clusters of identical structures have the same true diameter. Trumpler did not anticipate any space absorption, and only used the diameters of the clusters as a check on the distances calculated from apparent and absolute magnitudes on assuming space perfectly transparent. But it soon came out that the distances calculated by the latter method were systematically too large, and in such a way as to suggest the presence of an absorption term in (1), increasing fairly uniformly with increasing distance. The absorption found by Trumpler was $0^m.67$ per kiloparsec in the photographic region of the spectrum. His material gave also some information about the absorption in visual light, although only in the form of an indication.

He found the colour excess to be $0^m.32 \pm 0^m.03$ per kiloparsec. The absorption coefficient thus decreases with increasing wave-length, qualitatively in the way to be expected by ordinary Rayleigh scattering. This, however, is not quantitatively true, as we shall see later on.

Trumpler proposed as a working hypothesis that the absorbing matter is confined to a thin stratum in the plane of the Milky Way and with a thickness of the order a few hundred parsecs.

Trumpler's work was carried further by a number of different investigators. Schalén (*Arkiv för Mat., Astr. och Fysik*, **22**, A, No. 15; *Upsala Medd.*, No. 49, 1930; *Pop. Astr.*, **39**, 21, 1931) found a marked correlation between colour excess and distance for 22 stars in the direction of the open cluster NGC 663 in Cassiopeia, the result being a selective absorption of $0^m.26 \pm 0^m.06$ per kiloparsec. Van de Kamp (*A.J.*, **40**, 145, 1930) confirmed the existence of selective absorption by a study of colour excesses of A and B stars as a function of distance, and found a differential absorption of $0^m.355 \pm 0^m.031$ per kiloparsec for faint A and B stars, while Bottlinger's colour indices of bright B stars gave a value for the differential absorption of $0^m.267 \pm 0^m.031$ per kiloparsec. In the same paper Van de Kamp also derived a value for the total thickness of the absorbing layer of 175 ± 50 parsecs. Using Öhman's colour equivalents (*Upsala Medd.*, No. 48, 1930), Van de Kamp (*A.J.*, **41**, 84, 1931) gave as an improved value for the total thickness of the layer measured in differential absorption 210 ± 40 parsecs. In two later papers (*A.J.*, **42**, 97 and 161, 1933) Van de Kamp attempted to derive the total optical thickness of the absorbing layer by a study of the apparent distribution of globular clusters. He finds in this way an optical thickness of the layer of the order $0^m.8$. More detailed investigations of the optical thickness of the absorbing layer were made by Stebbins (*P.N.A.S.*, **19**, 222, 1933) by a careful study of the colour equivalents of globular clusters as a function of galactic latitude. If the absorbing matter is distributed with uniform density within a plane parallel stratum, the absorption suffered by the light from an outside object with galactic latitude β should obviously be proportional to $(\sin \beta)^{-1}$. This was also the basis of Van de Kamp's work, of course. The accurate determination of the constant of proportionality for both sides of the Milky Way gives at once the total thickness. Stebbins found a value of $0^m.1592$ for the total colour excess. Combining this value with the result of Trumpler, Van de Kamp and others of a colour excess of $0^m.32$ per kiloparsec within the absorbing layer, the effective thickness of the layer comes out about 500 parsecs.

E. T. R. Williams and Vyssotsky (*Ap. J.*, **77**, 301, 1933) also studied the colour excesses of globular clusters as a function of galactic latitude, and found a value of $0^m.114 \pm 0^m.02$ for the total colour excess of the absorbing layer by normal incidence.

Trumpler's value for the colour excess per kiloparsec was made more precise by the work of Miss Lois Slocum (*L.O.B.*, **15**, 123, 1931) and R. S. Zug (*L.O.B.*, **16**, 119, 1933). On using the so-called "half-colour filter method" proposed by Trumpler (*L.O.B.*, **14**, 89, 1929), Miss Slocum studied the star distribution in five selected areas in the Milky Way and

found a colour excess of $0^m.34$ per kiloparsec, and also an indication that this was 40 per cent. of the total absorption. Zug took special precautions in order to obtain a homogeneous system of colour indices, and determined magnitudes, colour indices and colour excesses in 23 galactic clusters. Zug gives a value for the colour excess of $0^m.36$ per kiloparsec, corresponding to an assumed uniform distribution of absorbing material in the neighbourhood of the Sun. He remarks, however, that a non-uniform distribution of material, depending on galactic longitude L according to the formula

$$\text{colour excess} = -0^m.10 + 0^m.36 \cdot r + 0^m.07 \cdot r^2 \sin(117^\circ - L), \qquad (3)$$

where r is the distance in parsecs, gives a considerably better representation of the observations. It was noted that two clusters at distances 4000 parsecs in galactic longitudes 27° and 79° respectively did not show markedly greater colour excesses than clusters in the same directions but only 2000 parsecs away, indicating a considerable thinning out of absorbing material at distances beyond 2000 parsecs in these directions. Zug's conclusions were criticised by P. ten Bruggencate (*Zs. f. Ap.*, **8**, 157, 1934) on the ground that the material used by Zug was insufficient to prove the existence of an interstellar absorption increasing uniformly with the distance.

Further work in the same direction was carried out by Samuel L. Thorndike (*L.O.B.*, **17**, 9, 1934) in a study of colour excesses of stars earlier than B3, but the results were rather inconclusive.

Colour Excesses of Planetary Nebulæ.—Another means of studying space absorption and reddening is afforded by the spectra of planetary nebulæ, both as regards the emission lines as well as the continuous background. The intensity decrements of the emission lines of hydrogen in these spectra were studied by Cillié (*M.N.*, **92**, 825, 1932) and interpreted on the basis of atomic theory. It was pointed out by Shajn (*Poulkovo Obs. Circ.*, No. 11, 8, 1934) that the decrement of the Balmer lines in these spectra showed a tendency to increase in steepness with decreasing galactic latitude, and interpreted this as an evidence of space reddening. This idea was taken up for a more detailed discussion by Berman (*M.N.*, **96**, 891, 1936), who confirmed Shajn's suggestion, and gave, as a result of his investigation, the following empirical formula for the absorption coefficient κ_λ as a function of the wave-length λ, per kiloparsec,

$$\kappa_\lambda = 0^m.53 \left(\frac{4862}{\lambda}\right)^{2.27}, \qquad (4)$$

where λ is expressed in angstroms. In the region of $H_\beta(\lambda = 4862)$ the absorption is thus $0^m.53$ per kiloparsec, and thus in reasonable agreement with other determinations. A thickness of the observing layer of 400 parsecs was assumed in these investigations.

The Zone of Avoidance.—Another way of studying the distribution of absorbing material in the galaxy is offered by the observed distribution of extra-galactic objects in the sky. Extra-galactic nebulæ are known to shun the Milky Way, leaving a central zone of avoidance where no nebulæ are found. This is well shown by the map of nebulæ drawn by Charlier

(reproduced in *H.B. der Astrophysik*, V/2, 1, Teil, p. 836). A preliminary discussion of the inferences which may be drawn from counts of nebulæ for different galactic latitudes was given by Van de Kamp (*A.J.*, **40**, 154, 1932). This work was far superseded by Hubble's extensive counts of extra-galactic nebulæ published shortly afterwards (*Ap. J.*, **79**, 8, 1934). These counts show a zone of avoidance averaging about 10° in latitude on either side of the central line of the Milky Way. This zone is bounded by zones of nebular deficiency on either side. A part of these deficiencies may represent chance fluctuations in the field. But taken as a whole, these zones can scarcely be explained except as absorption effects.

The irregularities in the zone of avoidance are interesting, as they show an unmistakable relation to the galactic centre and the anticentre. In the direction of the galactic centre, in the longitude interval 320° to 360°, the zone of avoidance flares up to about twice its normal width, which is about 10° in latitude on either side of the central line of the Milky Way. The other marked flare of the zone occurs in the Taurus region, where obscured regions of considerable extension are long known to exist. There is another flare in Cepheus between longitudes 60° and 100° which extends more than 20° in latitude, and the partial obscuration associated with this extension includes the North Pole. Forming mean values for the distribution of nebulæ for all longitudes and fitting these values on to a distribution following a cosecant law, Hubble found a total absorption by normal incidence to the galactic plane of $0^m.5$. No appreciable reddening of the nebulæ was observed for low galactic latitudes.

Hubble's results are interesting in many ways, and must be considered to supersede the results obtained from the study of globular clusters, in so far as it proved the extension of absorbing material to much higher latitudes than was formerly supposed to be the case. The far greater number of extra-galactic nebulæ, and their obvious independence of the galaxy itself, make them more suitable for work of this nature than the globular clusters. A detailed study of the luminosities and the colour excesses (if any) of nebulæ as a function of galactic latitudes would seem to be the next step. A first attempt in this direction was made by J. Dufay (*Journ. des Obs.*, **16**, 77, 1937) who investigated the run of the nebular luminosities as a function of galactic latitude, using the catalogue of nebulæ collected by Wirtz (*Lund. Obs. Medd.*, Ser. II, No. 29, 1923).

An extensive investigation of nebular magnitudes and colour indices has been published by Stebbins and Whitford (*Ap. J.*, **86**, 247, 1937). A selective absorption was detected, increasing with decreasing galactic latitude.

Irregularities in the Distribution of Absorbing Matter.—Although considerable doubt may still be retained with regard to detail, the existence of a thin layer of absorbing material along the plane of the Milky Way cannot be doubted. The next task is to find out something more about the distribution of the stuff within the layer. It is obvious that the assumption of a *homogeneous* plane parallel layer is not demanded by the observations themselves, but is only a simplifying assumption used as a first very rough approximation.

There is, as a matter of fact, plenty of evidence that the distribution is very patchy indeed, places of heavy obscurations, the dark nebulæ, alternating with transparent places, which in a few cases may provide a clear view diagonally through the Milky Way itself, the so-called "galactic windows." The distances of the condensations in the layer, the dark clouds, may be determined in principle from suitable star counts, but this has only been carried out in a few cases.

1. *The Coal Sacks* were analysed by E. v. d. Pahlen (*A.N.*, **238**, 269, 1929), A. Unsöld (*Harv. Bull.* 870, 1929), R. Müller (*Zs. f. Ap.*, **8**, 66, 1934) and H. Brück (*Zs. f. Ap.*, **8**, 75, 1934). The distance of the absorbing cloud was found to be about 150 parsecs, and the total absorption corresponds to about one magnitude.

2. *The Dark Nebulæ in Ophiuchus* were studied by R. Müller (*Zs. f. Ap.*, **3**, 261, 1931) and Åke Wallenquist (*Arkiv för Mat., Astr. och Fysik*, **25**, B, No. 28, 1937). The main nebula close to δ Ophiuchi has a distance of about 250 parsecs and a depth of about 400 parsecs, and produces a total absorption of about two magnitudes. It is preceded by a smaller cloud that sets in already at a distance of 100 parsecs. The nebula near ζ Ophiuchi begins to exert an absorption at a distance of about 200 parsecs, and its total optical thickness appears to correspond to $2^{m}.8$. The nebulæ near ξ Ophiuchi lies also at a distance of about 200 parsecs, and its optical thickness amounts to nearly one magnitude (R. Müller, *Zs. f. Ap.*, **4**, 365, 1932).

3. *Nebulæ in Taurus and Auriga.*—V. Klüber (*Zs. f. Ap.*, **6**, 259, 1933) finds a total absorption of the nebula of about $2^{m}.5$ and an extension in space from 300 to 1000 parsecs.

4. *The Cygnus Nebula.*—According to v. d. Pahlen (*Stellarstatistik*, p. 645), the distance of the elongated nebula in the vicinity of 52 Cygni is about 450 parsecs and its depth about 250 parsecs. According to H. Müller and L. Hufnagel (*Zs. f. Ap.*, **9**, 358, 1935), the selective absorption of the cloud is about 20 per cent. of the total absorption.

The region of the North America nebula was studied by E. Buch Andersen (*Ap. J.*, **38**, 275, 1913), who found a distance of about 150 parsecs. Wolf (*A.N.*, **223**, 89, 1924) gave the distance as 174 parsecs, but found that the strongest absorption set in at about 700 parsecs, and extended indefinitely on. This agrees fairly well with the subsequent work by Schalén (*Upsala Medd.*, No. 37, 1928, and No. 55, 1932), and Müller and Hufnagel (*Zs. f. Ap.*, **9**, 331, 1935).

At Poulkovo the Cygnus nebulæ have been subjected to a recent investigation by I. Balanovsky and V. Hase (*Bull. Obs. Poulkovo*, **14**, 2, No. 19, 1935). The region studied was that between γ Cygni and the veiled nebulæ NGC 6960 and 6992. The distances found for various areas of the nebular region range from 170 to 700 parsecs, and extensions in the line of sight from 200 to 350 parsecs.

5. *The Nebula near S Monocerotis* has, according to Wolf (*Seeligerfestschrift*, p. 312, 1924), a distance of about 450 parsecs and a depth of the same order.

6. *The Scutum Nebula* in the vicinity of the star cluster M 11 is interesting because it is so near that it has not been possible to locate its nearer boundary.

7. *The Dark Nebula near ξ Persei* has also been investigated at Poulkovo by I. N. Lehmann-Balamowskaja (*Bull. Obs. Poulkovo*, **14**, 1, No. 118, 1935). The cloud begins at about 260 parsecs and extends to about 450 parsecs. The following total absorption was found for the cloud :—

Photographic absorption	$0^m.4$
Selective ,,	$0^m.18$

8. *The Dark Nebula in Cepheus* was studied by Schalén (*Upsala Medd.*, No. 55, 1932) and M. Berg (*Bull. Obs. Poulkovo*, **15**, 2, No. 125, 1936). Schalén found two dark clouds in the main region of Cepheus, one behind the other, at a distance of 200 and 450 parsecs respectively, and with a total absorption of about 1^m. In the region investigated by Berg also two clouds were found at the respective distances of 250 and 800 parsecs. Evidence of space reddening was also found, the selective absorption being about half the general absorption in visual light.

9. *Galactic Windows.*—A glance at Hubble's zone of avoidance shows that regions exist quite close to the central line of the Milky Way where light from external galaxies slips edgewise through the galactic system. There is especially a field at galactic longitudes near 300° and extending from $-10°$ to $-16°$ in galactic latitude, which is very rich in faint external galaxies, and where Shapley has announced the discovery of 100 variable stars beyond the galactic centre at distances of about 23 kiloparsecs (*Harv. Bull.* 904, 1, 1936). Another transparent region, in the direction to the galactic anticentre, was announced recently by Shapley and Miss Boyd (*Harv. Bull.* 905, 7, 1937), the galactic co-ordinates of the region being about 138° longitude and latitude $+19°$.

The above rather incomplete review of irregularities in galactic visibility should suffice to show that the absorbing matter is very irregularly distributed. But the chance of discovery of dark nebulæ (see Kreiken, *Zs. f. Ap.*, **12**, 340, 1936) is so small for distances, say larger than 1000 parsecs, that the distribution of absorbing matter in interstellar space may be even more irregular than direct observations seem to indicate. The problem was proposed by Bottlinger (*Zs. f. Ap.*, **5**, 50, 1932) whether a distribution of dark clouds of the frequency observed in the vicinity of the Sun would account for the general absorption evidenced by the dimming of globular clusters and external galaxies. The answer was in the negative, however, if the clouds are assumed to be quite opaque.

In this report the words "absorption" and "scattering" have been used rather indiscriminately, since it is impossible to distinguish between absorption and scattering by studying the transmitted light only. If the interstellar absorption is due to scattering principally, it should be possible to observe a faint light in between the stars in those regions most affected by reddening effects. This scattered light should, accordingly, also be bluer than the incident star light. An attempt to discover directly the

scattered radiation was made by Elvey and Roach (*Ap. J.*, 85, 213, 1937). They reported to have observed an excess radiation from interstellar space, which they called the "galactic light," which is equal in luminosity to 57 stars of the tenth magnitude per square degree of the central line of the Milky Way. The next step would obviously be to determine the colour index of the galactic light to see if it were bluer than that from the majority of the stars. According to Jesse Rudnick (*Ap. J.*, 86, 212, 1937) the total colour index of the night sky is $0^{m}.65$, about the same as for the Sun. But this included light from a number of different sources. The colour index of the galactic light alone has thus far not been determined.

Constitution of the Absorbing Matter.—The absence of dynamical effects attributable to the dark matter in space shows that the total mass of this matter is not comparable to that of the stars as a whole. This gives an upper limit to the dimensions of the particles, as the screening effect of a cloud of spherical opaque particles of given mass is inversely proportional to the radius of a particle. As long as this radius is large in comparison to the wave-length of the incident light, the dimming of light will be the same for all wave-lengths practically, except for the fringe of radiation passing tangentially to the particles, where diffraction effects will come in depending on wave-length.

The presence of reddening effects shows at once that the dimensions of the obscuring particles are comparable with the wave-lengths of the scattered or absorbed light. The reddening effect affords therefore a basis for the determination of particle dimensions. Besides the dimensions, also an influence of the conductivity of the matter composing the particles may be anticipated. Sufficiently extended observations, preferably over the whole spectrum of the stars showing reddening effects, may therefore in time lead to interesting conclusions about the chemical constitution of interstellar matter.

For non-conducting particles small in comparison to the wav -lengths of the scattered light, Rayleigh's formula for the coefficient of scattering should hold :

$$\kappa = \frac{32}{3} \frac{\pi^3 (n-1)^2}{N\lambda^4},$$

where n is the index of refraction, N the number of particles in unit volume and λ the wave-length. In so far as n may be considered as constant in the frequency interval under consideration, this formula predicts a variation of κ proportional to the inverse fourth power of the wave-length. Writing $\kappa = k \cdot \lambda^{-4}$, the intensity of wave-length λ in the spectrum of a star should be affected by an absorption factor $e^{-\beta \cdot \lambda^{-4}}$, where

$$\beta = \int k ds \quad \text{and} \quad k = \frac{32}{3} \frac{\pi^3 (n-1)^2}{N},$$

the integral being extended from the observer to the star.

This formula of Rayleigh refers to a rather special case, and other possibilities must be considered, where the dimensions of the particles are com-

parable with the wave-length, and where the conductivity of the material is taken into account.

A revision of Rayleigh's theory in this direction was given by Mie (*Ann. d. Phys.*, **25**, 377, 1908) in a paper on the diffusion of light in a medium containing suspended spherical gold particles of dimensions comparable to the wave-length of the diffused light. The extinction coefficient is then given by a series of terms, which becomes very difficult to handle when the particle radius is of the order of the wave-length.

It was believed for some time that the observed reddening effect agreed with Rayleigh's formula (E. Schoenberg, *Mitt. Sternw. Breslau*, **3**, 1932; W. Gleissberg, *A.N.*, **246**, 1932). But later work soon proved that usually this is not the case. The most general results are those of Stebbins and Whitford (*Ap. J.*, **84**, 132, 1936). These authors studied the colours of 68 globular clusters with the 100-inch reflector at Mount Wilson. They found a close correlation between colour excess and space absorption. The maximum colour excess close to the zone of avoidance was found to be $0^m.82$, and the differential absorption from pole to pole $0^m.08$, corresponding to a total photographic absorption of $0^m.25$. The total absorption derived earlier by Hubble was $0^m.5$, and the authors showed that the difference between these results was too small to be accounted for by Rayleigh scattering. This disagreement may be due either to the particle dimensions being no longer small in comparison with the wave-length, or to absorption of light by the particles besides scattering.

A similar result was obtained earlier by Struve, Keenan and Hynek (*Ap. J.*, **79**, 1, 1934), who observed the spectral energy curves of two B stars, 55 Cygni and 13 Cephei, which are situated in the zone of avoidance in the Milky Way and which are known to be unusually red. These authors found it difficult to represent their results by a Rayleigh law of scattering, but found a lower power law, say scattering proportional to λ^{-2}, quite reasonable.

In some cases it seems that space absorption takes place without any appreciable attendant reddening effect. This is most marked in the bright reflection nebulæ, as was brought out by the work of Struve, Elvey and Keenan (*Ap. J.*, **77**, 274, 1933), and by other investigators of galactic nebulæ. Struve and his collaborators investigated the colour of the Pleiade nebula. If the transmitted light is appreciably reddened, the reflected light should be correspondingly bluer than the light source, just as the light from the setting sun is redder, while the light from the clear sky is bluer, than pure sunlight. The observed effect for the Pleiades, however, was very small, much smaller than would have been expected on assuming the reflection to be due to Rayleigh scattering. This means, as was pointed out by the authors, that the scattering particles must have dimensions which are comparable or large in comparison to the wave-length of the scattered light.

This result gave occasion to a paper by Greenstein (*Ap. J.*, **85**, 242, 1937), in which he pointed out that the pressure of the radiation from the nearby stars may have sifted out and removed a very large percentage of particle in the nebulæ which had dimensions small in comparison to the

wave-length of light. Greenstein based his work on Mie's theory of scattering in the form given it by Debye (*Ann. d. Phys.*, **30**, 57, 1909) in his work on the theory of radiation pressure.

Schalén (*Upsala Obs. Medd.*, No. 58, 1934, and No. 64, 1936), and E. Schoenberg and B. Jung (*A.N.*, **253**, 261, 1934), have attempted to determine the dimensions and the composition of the interstellar scattering particles by analysing the observed reddening effects of Mie's theory of scattering and absorption by metallic particles. Schalén's work is by far the most extensive in this respect. The calculations become very complicated for dimensions comparable with the wave-length of light. Assuming the particles to consist of iron—which may be a likely assumption considering the high abundance of iron in meteorites—Schalén finds the dimensions of the particles to be in the range of 500–1000 angstroms. Assuming a different kind of material for the particles other dimensions would result. At present it is not possible to determine both the chemical substance *and* the particle dimensions from observations on reddening alone, although it should be possible in principle.

Further progress in the field of interstellar absorption may be expected first of all by improving the accuracy of the present methods and by extending the investigations. Next, however, one should hope that fresh information may be obtained from a close co-operation with the workers in the field of meteors, especially the telescopic meteors, which are now known to be preponderantly interstellar in origin, and to show a preferential motion in interstellar space (*cf.* C. Hoffmeister, "Das interstellare System der Kleinkörper," *Sitz. Ber. Preus. Akad. Wiss.*, **18**, 1936).

Svein Rosseland.

LINE PROFILES

The study of line profiles is closely bound up with all our ideas of stellar atmospheres, and, as our knowledge with regard to the latter is still in a state of rapid growth, so our views concerning the structure of lines in stellar spectra are steadily developing. The present account, which is intended to give a fairly general review of the subject of line profiles as it stood at the end of 1937, is therefore no more than an interim report. A good deal of work connected with stellar atmospheres, including the whole question of ionization, has of necessity been omitted, while other matters at present attracting much attention, *e.g.* multiplets, "curves of growth", etc., have scarcely been mentioned. It has been thought best to confine discussion of observational technique to a shorter section 2, which is independent of section 1.

1

General Theory.—We define the line profile or contour as a curve in which ordinates are light intensities within a spectrum and abscissæ are wave-lengths or frequencies (or, occasionally, velocities in the line of sight). Taking the problem of measuring the profile as solved, we have to inquire how the observations are brought into relation with the theories of stellar atmospheres, the rotations and expansions of stars, etc. For the present we confine our attention to absorption spectra.

The theory of formation of absorption lines as now generally adopted is based on contributions from a considerable number of investigators, ranging from Schuster and Schwarzschild in the past, down to Milne, Eddington, Unsöld, Pannekoek and numerous others in the present day. The general method is to consider a model atmosphere, in which radiation is being absorbed and emitted according to physical laws, supposed known, and to calculate the outflow of radiation from the surface, the results being compared with observation as far as is possible. Since the processes taking place in a normal stellar atmosphere are not less complicated than, for instance, those in the terrestrial atmosphere, it is easy to realize that any theoretical atmosphere represents a rather drastically simplified state of affairs.

Standard theory postulates an atmosphere (1) stratified in uniform plane parallel layers, (2) motionless except for thermal motions of individual atoms, electrons, etc., (3) generating no energy, (4) forming only one absorption line, which arises from transitions in an atom with only two energy levels. It is usually also assumed that the atmosphere is in local thermodynamical equilibrium; in other words, that the emission of radiation in the continuous spectrum obeys Kirchoff's law. The behaviour of the atmosphere is described by (*a*) a coefficient of continuous absorption, k_ν,

which varies only slowly with frequency, so that it may be considered constant with respect to ν in the neighbourhood of one particular line. The atomic process chiefly responsible is ionization and recombination; at lower temperatures molecular dissociation may also play a part. (*b*) A coefficient of line absorption or scattering, l_ν, which comes to a maximum at the centre of the line, falling at first rapidly and then more gradually to zero on either side. The atomic process is the familiar one of excitation by the absorption of a quantum of radiation, followed by the loss of the same quantum, either by re-emission or by a collision. (*c*) A quantity, ϵ, representing the fraction of atoms de-excited by collisions. ϵ is usually regarded as small and is often taken to be zero. Some writers prefer to distinguish the line scattering and absorption by independent symbols, such as $\sigma_\nu[=l_\nu(1-\epsilon)]$ and $\kappa_\nu[=l_\nu\epsilon]$ respectively.

The procedure adopted by various authors differs considerably in detail, but the fundamental plan of attack is always the same. An equation of transfer of radiation is formed, which is simply an expression of the fact that the amount of energy entering a certain small volume of the atmosphere equals the amount leaving the same volume during the same time. For example, we may quote Eddington's equation of transfer: *

$$\cos\theta\,\frac{d\mathcal{J}_\nu'(\theta)}{\rho dr} = -(k_\nu+l_\nu)\mathcal{J}_\nu'(\theta)+(1-\epsilon)l_\nu\mathcal{J}_\nu'+\epsilon l_\nu\mathcal{J}_T+k_\nu\mathcal{J}_T,$$

θ is the angle between the line of sight and the normal to the atmospheric layers, ρ is density, r is distance measured outwards along the normal, $\mathcal{J}_\nu'(\theta)$ is the intensity of radiation in direction θ and at frequency ν within the line, $\mathcal{J}_\nu(\theta)$ the corresponding intensity just outside the line, $\mathcal{J}_\nu' = \frac{1}{4\pi}\int\mathcal{J}_\nu'(\theta)d\omega$ and $\mathcal{J}_T$ is the equilibrium value of $\mathcal{J}$ for temperature T, *i.e.* is given by Planck's law. The equation may also be written

$$\cos\theta\,\frac{d\mathcal{J}_\nu'(\theta)}{d\tau} = (1+\eta_\nu)\mathcal{J}_\nu'(\theta)-(1-\epsilon)\eta_\nu\mathcal{J}_\nu'-(\epsilon\eta_\nu+1)\mathcal{J}_T$$

where $\tau = -\int k_\nu\rho dr$, the optical depth measured downwards from the surface, and $\eta_\nu = l_\nu/k_\nu$.

The solution of the equation of transfer is generally made with the aid of one of two approximations: (1) We follow Schuster and Schwarzschild, as Milne has done in much of his work, divide the radiation stream into two parts, the one stream outwards, the other (becoming zero at the surface) inwards, each directed perpendicular to the surface and independent of θ, $\cos\theta$ being replaced by a mean value $\frac{1}{2}$. (2) Alternatively we may use the approximation introduced by Eddington $\frac{1}{4\pi}\int\mathcal{J}(\theta)\cos^2\theta d\omega = \frac{1}{3}\mathcal{J}$. This is rather more accurate than the Schuster-Schwarzschild method, but according to Pannekoek † the difference between the two is small, amounting at the

* *M.N.*, **89**, 620, 1929.
† *M.N.*, **91**, 140, 1931.

centre of a spectrum line to 15 per cent. of the intensity there. The inaccuracy of either approximation is negligible compared with the purely physical uncertainties inherent in the theory. Indeed, the theory of formation of the continuous spectrum involves a very similar, but rather simpler, equation of transfer, and this has been studied both by these approximations and by means of a strictly accurate solution, one of the results being to show that the errors of the approximations are on the whole inconsiderable. For the development of the mathematical side of the theory the reader should consult Milne * or Hopf.†

To produce a solution for the equation of transfer, one needs to make further assumptions relating to the physical state of the atmosphere, and, if an algebraical solution is sought, to choose these so as to reduce the equation to a standard differential form. The usual cases are given by Eddington in his paper, viz.:

(i) η_ν and ϵ constant with respect to τ and $\mathcal{J}=\mathcal{J}_T$ just outside the line.

(ii) η_ν and ϵ constant with respect to τ and $\mathcal{J}_T=a+b\tau$.

(iii) $\dfrac{1}{1+\eta_\nu}=\alpha+\beta\tau, \qquad \epsilon=0, \qquad \mathcal{J}=\mathcal{J}_T$ outside the line.

(iv) $\dfrac{1}{1+\eta_\nu}=\alpha+\beta\tau, \qquad 1+\epsilon\eta=C, \qquad \mathcal{J}=\mathcal{J}_T$ outside the line.

A method has been developed by Strömgren ‡ for solving the equation of transfer analytically under rather more general conditions. Essentially the process consists of starting with one of the usual solutions and working from it by the use of standard perturbation methods to other cases, such as, for instance, where $\lambda_\nu=\dfrac{1+\epsilon\eta_\nu}{1+\eta_\nu}$ is variable with depth. The errors depend on the size of the deviations from the conditions of the original solution, but in actual applications the accuracy appears to be sufficient for a number of cases of practical importance, so that the method promises to be of considerable utility.

A solution valid in the wings of a line, *i.e.* for regions where the line scattering and absorption coefficients are much smaller than the continuous absorption coefficient, but all three varying in any manner with τ, has been worked out by Unsöld.§ His method avoids using the Schuster-Schwarzschild or Eddington approximations, and his results hold good down to line intensities about 85 per cent. of the continuous spectrum, except near the limb ($\cos\theta < 0{\cdot}2$). Among other things Unsöld shows how the mode of variation of the line wing from centre to limb of the Sun's disc is chiefly dependent on the nature of the variation of η and ϵ with τ. Minnaert || has given an alternative analysis, avoiding the assumption of linear variation of $\mathcal{J}_T$ with τ and obtains a result effectively identical with Unsöld's for the outer wings of a Fraunhofer line.

* *Handbuch der Astrophysik*, III/1, 96, 1930.

† "Mathematical Problems of Radiative Equilibrium," 1934, *Cambridge Mathematical Tracts*, No. 31.

‡ *Ap. J.*, **86**, 1, 1937.

§ *Z. f. Ap.*, **4**, 339, 1932.

|| *Z. f. Ap.*, **12**, 313, 1936.

A criticism which may be levelled against the standard solutions of the equation of transfer is that the variation with τ which is postulated for η_ν, ϵ, $\mathcal{J}_T$ is conditioned more by a desire to obtain a straightforward algebraic solution than by considerations of physical reality. Pannekoek, in a well-known series of papers,* has avoided this charge by using theoretical formulæ for k_ν, etc., working out numerical values for the required depths and integrating the equation of transfer numerically. The difficulty now encountered is that the theories invoked cannot be regarded as in any way complete, particularly with regard to the continuous absorption. The present state of the study of the colour distribution in stellar spectra and of the darkening to the limb in the Sun is sufficient evidence that our knowledge concerning the continuous absorption coefficient is still quite imperfect. Laboratory experiments as well have shown that the usual opacity formulæ cannot be applied to all elements ; † indeed, there is as yet no very good experimental evidence that they are sufficient with even hydrogen.

The use of theoretical formulæ, however, is on a more satisfactory footing with regard to the line absorption. In studying the profile of a single line what we are chiefly concerned with is the variation of l_ν with ν. (As pointed out earlier, the change of k_ν with ν in the region of one individual line is negligible.) The formula universally employed is

$$l_\nu \rho = \frac{f_{ki}\dfrac{Ne^2}{m}\delta_{ik}}{(\nu-\nu_{ik})^2+\delta_{ik}{}^2},$$

or its classical predecessor, the radiation damping formula,

$$l_\nu \rho = \frac{\dfrac{Ne^2\gamma}{cm}}{(\nu-\nu_0)^2+\gamma^2},$$

f_{ki} is the oscillator strength of the line formed by transition between atomic energy levels i and k, N is the number of atoms per c.c., e, m are the charge and mass of the electron, δ_{ik} is the natural line width, ν_{ik} or ν_0 is the frequency of the line centre, ρ is the density of matter, γ is the radiation damping constant, $\dfrac{8\pi^2e^2\nu_0{}^2}{3mc^3}$. Laboratory measurements on the D lines of sodium (in absorption) by Korff ‡ and on the potassium resonance lines $\lambda\lambda$ 7665, 7699 by Heard, § have confirmed the formula over a range of N limited only by observational conditions. It is also found that the line profiles calculated with the formula agree with the outer parts of the profiles of resonance lines in the solar spectrum, a result we owe originally to Unsöld. ||

* *M.N.*, **91**, 139, 519, 1931; *Publications of the Astronomical Institute of the University of Amsterdam*, No. 4, 1935.

† *E.g.* Ditchburn, *Proc. Roy. Soc.*, **117** A, 486, 1928 ; **143** A, 472, 1934 ; **157** A, 66, 1936.

‡ *Ap. J.*, **76**, 124, 1932.

§ *M.N.*, **94**, 458, 1934.

|| *Z. f. P.*, **46**, 765, 1928.

By the use of one of the above expressions for the scattering coefficient it is possible to deduce the number of atoms effective in producing a given absorption line. The method was initially suggested by Stewart,* but Unsöld has been responsible for its development and successful application. Initially he used the Schuster model of a purely scattering atmosphere ($k_\nu = 0$, $\epsilon = 0$) superposed over a photosphere, and by fitting the outer parts of theoretical and observed profiles was able to deduce $\int_0^x N dx$, *i.e.* the effective number of absorbing atoms above 1 cm.^{2} of photosphere. The result was roughly of the order of 10^{18} for lines such as H and K, D_1 and D_2, λ 4227 *Ca*. The meaning of the phrase "number of atoms above the photosphere" was later clarified by Milne † on the basis of a more general atmospheric model.

Since the atoms of the atmosphere are in thermal motion, and not at rest, the scattering coefficient has to be modified to include the resulting Doppler effect. This has been done by a number of writers, Voigt's formula being the one most often utilized. ‡ In the absence of a Doppler effect, or in the case of very strong lines, where Doppler effect is relatively negligible, the integrated intensity I of a line varies very nearly as the square root of the number N of absorbing atoms, so that the so-called "curve of growth", the graph of log I plotted against log N, is a straight line of slope $\frac{1}{2}$. In the presence of atomic motion, however, as Schütz § first emphasized, the breadth of weak lines is due primarily to Doppler effect and not to radiation damping; then the integrated intensity increases directly as the number of atoms and the curve of growth has a slope 1. Between the two approximately straight sections of the curve of growth is a point of inflexion in whose neighbourhood the slope of the curve is smallest. The general form of the curve has been confirmed by observation of multiplets. ||

In the case of the Sun the lines whose shapes are conditioned practically entirely by Doppler effect happen to be too narrow for their profiles to be measurable with any accuracy. The strongest lines in the solar spectrum should be very little affected by the thermal motions, and, owing to the very high theoretical value of the scattering coefficient at its maximum, the line centres should be very black, with intensities less than 1 per cent. of the continuous spectrum. For some years this proved a stumbling-block, as the observed central intensities were rarely less than 10 per cent. However, this appears to have been due in most cases to observational errors, as the later and more accurate measurements of Allen, ¶ Thackeray ** and Redman †† all go to show that the strong metallic lines can have central intensities well under 5 per cent., Redman's measures going as low as

* *Ap. J.*, **59**, 30, 1924.
† *M.N.*, **89**, 3, 1928.
‡ *München Ber.*, 603, 1912.
§ *Z. f. Ap.*, **1**, 300, 1930.
|| *E.g.* Minnaert and Mulders, *Z. f. Ap.*, **2**, 165, 1931; see also Minnaert, *Observatory*, **57**, 328, 1934.
¶ *Memoirs of the Commonwealth Solar Observatory, Canberra*, No. 5, parts 1 and 2, 1934.
** *M.N.*, **95**, 293, 1935.
†† *M.N.*, **95**, 742, 1935; **97**, 552, 1937.

2 per cent., a figure which can be explained by a comparatively modest amount of turbulence, as will be mentioned later. The hydrogen lines, on the contrary, are outstanding in showing high central intensities, which cannot be attributed to observational error, and here some other explanation must be sought.

On the whole, it may be claimed that theory gives a not unsatisfactory explanation of Fraunhofer lines observed at the centre of the Sun's disc. A more rigorous test is to compare the profile changes between centre and limb with those predicted by theory. Less attention has been paid by observers to this important method than it has deserved. Plaskett's well-known work on the *Mg b* lines * showed that the observed centre to limb variation could not be reconciled with the case of "pure absorption" ($k_\nu = 0$, $\epsilon = 1$), or of "pure scattering" ($k_\nu = 0$, $\epsilon = 0$). Even with a model combining both absorption and scattering, difficulties were encountered. Wiles † later rediscussed Plaskett's observations and showed that line profiles determined with any reasonable accuracy could not yield precise values of η and ϵ. More recently Minnaert and Houtgast ‡ have observed a few well-known lines from centre to limb and failed to get satisfactory quantitative agreement with theory. They find, *inter alia*, that the linear approximation $\mathcal{J}_T = \alpha + \beta\tau$ is not sufficiently accurate. In general, line wings are stronger near the limb than theory demands, "as though the concentration of selectively scattering gases at the surface relative to lower levels is greater than according to theory". They were unable to find any satisfactory explanation for this.

Woolley § recently has expressed the opinion that the most crucial test of any theory of line formation must come from comparison with observations made at the extreme limb near the total phase of an eclipse of the Sun. Thackeray ‖ has studied slit spectrograms obtained by the Cambridge expedition to Japan in 1936, and from these has given diagrams showing typical lines in the transition stages from Fraunhofer absorption to chromospheric emission, while Woolley has had some success in producing theoretical profiles of qualitatively similar outline. This work needs to be pursued further, but the observations demand more powerful spectrographic equipment than has ever yet been taken to an eclipse.

As an alternative to the method of computing profiles on the basis of some model, with an assumed relation of various parameters to optical depth, it is in principle possible to deduce η and ϵ as functions of τ by observations of the profile changes from centre to limb. ten Bruggencate ¶ has indicated one way of doing this, and another method is at present in course of actual application by Plaskett.** It would seem that, given the necessary accumulation of precise observations, this line of attack is likely to prove far more fruitful than any other, although the insensitivity of the profile to changes of the course of η with optical depth is a rather serious difficulty.

* *M.N.*, **91**, 870, 1931. † *M.N.*, **92**, 401, 1932. ‡ *Z. f. Ap.*, **12**, 81, 1936.
§ *M.N.*, **98**, 3, 1937. ‖ *M.N.*, **97**, 672, 1937. ¶ *Z. f. Ap.*, **4**, 159, 1932.
** *Oxford University Observatory Annual Report*, 1937.

Centre to limb profile observations in stellar spectra are at present entirely beyond our technical resources, except possibly in the case of a few eclipsing variables. Redman * has measured the change of integrated intensity of the hydrogen lines from centre to limb in spectra of type near Ao by observing two selected Algol stars during partial eclipse, and with improved equipment it is conceivable that some information might be obtained in this way with regard to the line profiles.

Turbulence.—A star's atmosphere is not in fact the idealized entity envisaged in theory, and of the factors which may modify the results of the standard theory one of the more likely is turbulence. Some years ago McCrea † sought to explain the low density gradient in the chromosphere by postulating a kind of turbulence such that atomic velocities are greater than those given by the normal theory of gases at the temperature of the solar surface. There is actually some observational evidence for turbulence in the chromosphere, since the lines of its emission spectrum, according to Unsöld ‡ and to Menzel § have widths corresponding to velocities of the order of 15 km./sec., which is considerably greater than the thermal velocities, even in the case of hydrogen. The measurements are very difficult to make, with self-absorption in the line and instrumental distortion present, and eclipse observers could with profit pay more attention to this problem.

However, we are likely also to encounter turbulence in the layers below the chromosphere which are chiefly responsible for the formation of absorption lines. If present, the central intensities of the Fraunhofer lines will be raised. We may follow Allen || and distinguish between a "small-scale turbulence" and a "large-scale turbulence". The first is of the kind just mentioned, affecting the motions of individual atoms, and the resulting line profile is computed by modifying the scattering coefficient in the same way as is done for the thermal motions. The "large-scale turbulence" arises from the bodily motion of masses of gas whose diameters are taken to be much greater than the depth of the layers contributing to the formation of the line. Owing to poor seeing, our spectrograph slits always take in light from a considerable number of these areas at once. The velocities in the line of sight are supposed to have an error distribution, the effect on the spectrum being derived from the superposition of a group of undistorted Fraunhofer lines, scattered about a mean position with the appropriate distribution. The increase of the central intensity of a line is, for a given average velocity in the line of sight, not the same for large-scale as for small-scale turbulence; in the case of strong lines, large-scale turbulence is the more effective. Allen's observations in the red and infra-red are consistent with either a small-scale turbulence of 1·5 km./sec., or a large-scale turbulence 1·8 km./sec., of which the latter agrees well with the large-scale 1 to 1·5 km./sec., found by Redman from central intensities of strong metallic lines in the violet.

* *M.N.*, **96**, 488, 1936. † *M.N.*, **89**, 718, 1929.
‡ *Ap. J.*, **69**, 209, 1929; *Z. f. Ap.*, **3**, 77, 1931.
§ *Lick Observatory Publications*, **17**, 296, 1931.
|| *Ap. J.*, **85**, 165, 1937.

The irregular and granular nature of the Sun's surface, observed in white light or with the spectroheliograph, makes the introduction of a moderate amount of turbulence into our ideas appear quite reasonable. Our knowledge in this respect is, however, in a very elementary state. The problem has still to be faced as to what happens if there is a turbulence neither small- nor large-scale, but of some intermediate nature. With regard to turbulence in stellar atmospheres we are still more in the dark. It has been fashionable lately to attribute several unexplained observations in stellar spectroscopy, *e.g.* anomalous intensities in multiplets, to "turbulence", without very much supporting evidence. Needless to say, this is a course to be followed only with caution.

Interlocking and Fluorescence.—One of the most valuable features of Eddington's classical 1929 paper was the stress laid on the physical assumptions underlying the standard theory of formation of absorption lines. Among these is the supposition that the absorption of a quantum Q of light in the region of the line is followed by the emission of an identical quantum Q, and, conversely, that the emission of a Q presupposes the absorption of a Q. In the case of a resonance line it is generally understood that the lower energy level (the ground state of the atom) is nearly perfectly sharp, and furthermore that a transition from the upper level is far more likely to be into the ground state than into any other, so that the assumed conditions are complied with fairly closely. But in general there are three separate possibilities: (*a*) an atom may go from state A to state B and return to a point of state A other than that from which it started ("non-coherent scattering"), (*b*) it may go from A to some other state and then by a series of transitions from level to level, finish up with the transition *B* to A (a case of "interlocking"), (*c*) it may be ionized from A and recombine at a higher level, cascading down and again finishing with the transition B to A ("fluorescence").

Non-coherent scattering has been discussed by Woolley,* Pannekoek,† Minnaert,‡ and Spitzer.§ The last named has included the simplest case of interlocking and examined the behaviour of a three-level atom on the basis of the Weisskopf-Wigner theory, showing that the effect on an absorption line, a filling up of the centre, is likely to be rather small. The necessary calculations seem to be feasible only in very simplified cases.

Interlocking has been investigated by Woolley‖ and by Pannekoek,¶ and fluorescence by the same writers and also by Strömgren.** Both effects indicate a lack of thermodynamical equilibrium in the layers concerned, which may be attributed both to the presence of an absorption line and to the fact that radiation at the star's surface is subject to a dilution factor $\frac{1}{2}$. The effect to be expected on line profiles in the part of stellar spectra that we observe is a raising of the central intensity. Resonance lines should

* *M.N.*, **90**, 779, 1930.
† *Proc. Roy. Acad. Sci. Amsterdam*, **34**/2, 1353, 1931.
‡ *Z. f. Ap.*, **4**, 153, 1932. § *M.N.*, **96**, 794, 1936.
‖ *M.N.*, **94**, 631, 1934; *Observatory*, **57**, 345, 1934.
¶ *M.N.*, **95**, 725, 1935. ** *Z. f. Ap.*, **10**, 237, 1935.

be practically immune to any influence of interlocking, but not necessarily to that of fluorescence. On the Sun, neither seems to have raised appreciably the central intensities of either resonance or low excitation metallic lines. The hydrogen Balmer lines and perhaps other high excitation lines (which are observed by Allen to be systematically less sharp than low-level lines) may be affected. Woolley computes that central intensities of the order of 20 per cent. might be produced in $H\alpha$ and $H\beta$ by fluorescence, the observed values being 15 per cent. Strömgren's work in effect deals with the influence of fluorescence on resonance lines. He finds that while high central intensities can be explained qualitatively, our lack of knowledge concerning atomic transition probability coefficients makes quantitative calculation very difficult.

Stark Effect.—For many years it has been suggested that Fraunhofer lines might be broadened by pressure, or, what amounts to the same thing, by the Stark effect arising from inter-atomic electric fields, but it was not until comparatively recently that Struve produced with the collaboration of Elvey convincing evidence for the presence of this phenomenon in stellar spectra.*

Since the effect decreases rapidly with increasing atomic weight, it is found strongly marked only with the lightest elements, hydrogen and helium. The distinctive character of the hydrogen lines in A stars is well known, while even in the Sun their wings extend very widely, in a manner entirely different from the strong metallic lines. Computations of hydrogen line profiles, using the Holtsmark formulæ for Stark effect, have been made by Verweij,† who tabulates his results as a function of the temperature and the gravitational acceleration in the star's atmosphere. For the less luminous A-type stars there is general agreement with the observations of E. T. R. Williams, Elvey, and E. G. Williams, and the predicted variation with g is qualitatively the same as that observed. With stars of great intrinsic luminosity, of all spectral types, theory and observation are difficult to reconcile. On the Sun, $H\beta$, $H\gamma$ and $H\delta$ agree with theory, but $H\alpha$ is much narrower than expected.

An important feature of this work lies in the fact that once the theory can be demonstrated to be reliable and in general agreement with observation, the measured hydrogen profiles together with a known surface temperature are sufficient to provide a value of g. Applications should be of great value, particularly in the case of white dwarfs.

It may be noted that Stark effect according to Verweij's work can account satisfactorily for the extensive wings of the hydrogen lines, but not for their high central intensities.

Line Blends.—The majority of absorption lines in stellar or solar spectra are neither so much stronger than, or so remote from, their fellows that they can be considered as completely independent as theory ordinarily supposes. In other words, we have to be able to reconcile theory and

* *Ap. J.*, **70**, 141, 1929 ; **72**, 277, 1930 ; **74**, 225, 1931.

† *Publications of the Astronomical Institute of the University of Amsterdam*, No. 5, 1936.

observation in the case of blended as with isolated lines. The study of blended lines from the point of view of their shapes and intensities is a natural, but quite recent, development and it is too early yet to make any final judgment in the matter. Available observations are somewhat contradictory, but so far there is no clear case for modifications of our theoretical ideas.

Swings and Struve * have measured the intensities of *O*II lines within $H\gamma$ and of the *Ca*II H line within $H\epsilon$ in spectra of types Bo to Ao, and found rather serious disagreement with computed intensities. These results have led to a suggestion that atoms in a stellar atmosphere are to some extent stratified and a number of the consequences of such a hypothesis have been worked out by Swings and Chandrasekhar.† There is, however, reason to doubt the accuracy of the observations, since a repetition of some of them by Wilson and Thackeray,‡ namely, those of the H line within $H\epsilon$ in α Lyræ, provided satisfactory agreement with theory. Further, the central intensity of H was equal to that of the unblended K line, as would be expected.

Thackeray § has made a careful investigation of an iron multiplet in the solar spectrum, some of whose members lie within the K line. This permits a good idea to be obtained of what would have been the behaviour of the blended lines had K been absent, and assists the observer to assess more accurately what have been the effects of the blending. Thackeray finds that except for the weakest lines the central intensity, measured relative to the continuous spectrum, is unaltered. The behaviour of the lines, except for those which are severely blended, is on the whole in accordance with the predictions of a straightforward extension of standard theory. The upper state corresponding to a blended line must be relatively deficient in atoms, and one would anticipate that the behaviour of other lines connected with this state would be affected, but so far the observations have given no confirmation of this.

Non-static Atmospheres.—One of the most serious criticisms to be brought against the normal theory of line formation is that it postulates a static atmosphere, whereas we know from direct observation of the surface of the Sun that this is not perfectly true. We have already considered the question of turbulence and should also give attention to cases where there may be a stream of matter leaving the star. McCrea and Mitra ‖ have studied the problem of scattering of radiation in a medium in non-uniform motion, taking the particular case of a scattering atmosphere surmounting a photosphere and having an outward velocity which is function only of height above the latter. Qualitatively it can be seen that any spectrum line will be shifted to the violet and unsymmetrically broadened, so that the red side is steeper than the violet. An attempt to obtain a solution more precise than that from qualitative reasoning shows that the problem is so complicated as to be intractable except under drastic simplifications. It is of

* *Ap. J.*, **83**, 238, 1936.
† *M.N.*, **97**, 24, 1936.
‡ *P.A.S.P.*, **48**, 329, 1936.
§ *Ap. J.*, **84**, 433, 1936.
‖ *Z. f. Ap.*, **11**, 359, 1936.

considerable interest to note that a few lines from the centre of the Sun's disc have been found by several independent observers to be slightly unsymmetrical and that the asymmetry is always in the sense just described.* One is led to wonder what is the effect on the very accurate wave-length measurements required for studying the red shift in the solar spectrum.

The distortion of an absorption line which would be seen in integrated light from the disc of an expanding star has been worked out by Carroll † and by Wilson.‡ The effect on the line is one of displacement and distortion, the amount of the latter depending on the size of the velocity relative to the width of the line. Roughly speaking, if the Doppler shift corresponding to the velocity of expansion is not greater than the half width of the line, the result is mostly displacement with little distortion ; if the velocity is great relative to the half width, there is appreciable asymmetrical broadening. For practical purposes, the question has to be considered in relation to the spectrographic resources available for the necessary observations, since instrumental distortion can easily swamp the changes of line shape produced by moderate velocities.

A more popular side of the question of moving atmospheres is encountered when we turn to novæ and related stars, where, of course, one is dealing predominantly with an emission, not an absorption line spectrum. Nearly twenty years ago Shapley and Adams suggested that in cases like these the characteristic broadened band-like lines were formed by matter being ejected by the star. Attention was brought back to the subject within recent years mainly by the work of Beals,§ initially concerned with the profiles of bands in Wolf-Rayet spectra. He found that most of these were substantially flat-topped, and showed that a rectangular-shaped line profile could be produced by an envelope of material, ejected with uniform velocity from a small central star and transparent to its own radiation. The profile is provided with sloping instead of vertical sides by assuming a scatter in the velocities of the atoms. The model also gives a direct explanation of the absorption line frequently observed on the more refrangible edge of the band.

The advent of Nova Ophiuchi and Nova Herculis stimulated discussion of the problem, especially in its application to novæ. Gerasimovič,‖ Chandrasekhar,¶ and Wilson** have worked out the profiles of emission lines formed by expanding envelopes, the velocities in which are given by various simple formulæ. Applications to actual novæ and attempts to derive from profile measurements what have been the velocities in the supposed expanding shells of gas, have served chiefly to stress the complexity of the problem, for which as it stands at present there can be no unique solution. The theoretical profiles are always based on the suppositions that the star and envelope are spherically symmetrical and are not rotating, while the envelope is taken to be transparent to its own radiation. As far

* *M.N.*, **97**, 571, 1937.
† *M.N.*, **88**, 548, 1929.
‡ *Ap. J.*, **82**, 233, 1935.
§ *Publ. D.A.O. Victoria*, **6**, No. 9, 1934.
‖ *Z. f. Ap.*, **7**, 335, 1933 ; **10**, 154, 1935 ; *M.N.*, **94**, 737, 1934.
¶ *M.N.*, **94**, 522, 1934.
** *Ap. J.*, **80**, 259, 1934.

as novæ are concerned we have no guarantee that any of these assumptions is even approximately correct. Wilson and Williams * found it difficult to explain their observations of N. Ophiuchi, while Williams † has recently found it equally impossible to reconcile with any simple model the behaviour of the band profiles in N. Herculis during its early development.

An outstanding source of perplexity in work of this kind is the question of deciding to what extent a profile continues to represent the same group of atoms from day to day. Precisely the same changes of spectrum might be caused by (1) atom groups respectively having constant radial velocities *a*, *b*, *c*, . . . passing in succession through the state of excitation necessary to produce a certain line *L*, or (2) the same atom group remaining always capable of producing *L* and going through the velocity states *a*, *b*, *c*, . . . This kind of difficulty is of a very general nature. We find examples in other branches of astrophysics, as when we come to study the line of sight velocities in Cepheid spectra, or to interpret the apparent motions in monochromatic kinematograph pictures of solar prominences.

Emphasis was laid by Chandrasekhar on the effect of the occultation of a part of the envelope by the disc of the parent star, and he calculated the resulting asymmetry of the band profile in certain cases. However, Beals ‡ has pointed out that the effect is completely masked for purposes of observation by the absorption at the violet edge of the band, due to matter lying between the observer and the star disc, and there seems no hope of measuring the asymmetry, even in the relatively favourable case provided by P Cygni.

Stellar Rotation.—In the case of the normal star, where we observe light integrated over the whole disc, axial rotation may broaden all lines of the spectrum. That this could occur has been realized from the earliest days of stellar spectroscopy, but only with the increasing mass of material coming to hand in fairly recent years has it been possible to put the question on a reasonably sound footing. As with Stark effect, most of the observational evidence has come from the work of Elvey § and Struve ‖ at the Yerkes Observatory.

The broadening of a spectrum line by Stark effect is confined, as far as appreciable effects go, to lines of hydrogen and helium, so that the observer is fairly safe in attributing to rotation the broadening of lines of heavier elements, such as *Mg*II λ 4481 in early type spectra. The fact that spectroscopic binaries so often have broadened lines, and almost invariably so when the orbital period is short, is the strongest evidence for explaining the distortion by rotation and not by some form of turbulence. Confirmation is given by the circumstance that the line profiles are generally consistent with the supposition that the periods of axial rotation of the components are the same as that of the orbital motion. Struve and Elvey have been able, by assuming an undisturbed profile and then by distorting according to given rotational velocities, to fit the observed "dish-shaped" profiles in

* *Ap. J.*, **80**, 344, 1934.
† *M.N.*, **97**, 612, 1937.
‡ *Observatory*, **57**, 378, 1934.
§ *Ap. J.*, **70**, 141, 1929 ; **71**, 221, 1930.
‖ *Ap. J.*, **72**, 1, 1930.

many stars. Except in the case of eclipsing variables, we do not know the orientation of the rotational axis, so that all that can be deduced is the quantity $V \sin i$, where V is the equatorial velocity and i the inclination of the axis to the line of sight.

The striking correlation of rotational broadening with spectral type has been commented on by Struve, and investigated statistically by Westgate,* who finds that A-type stars have greater rotational velocities than B or F stars, while appreciable rotation disappears between F2 and F5. That very small or zero rotational velocities should be observed in the overwhelming majority of late type stars is one of the most astonishing facts of observational astrophysics, and is so far entirely without explanation.

Carroll † has elaborated methods whereby rotational velocity may be derived from a measured profile without assuming the original undisturbed shape of the line. His analysis demonstrated that a spectrum line broadened by rotation must have certain characteristic features in its shape which can be revealed by suitable mathematical treatment. For instance, if $O(t)$ is the observed rotationally broadened line, and $t = \dfrac{\lambda - \lambda_m}{\lambda_m}$, λ_m being the mean wave-length of the line, then $\int_{-\infty}^{+\infty} O(t) \cos ut \, dt$ should have its first four zeros at $u\beta = 4{\cdot}147$, $7{\cdot}303$, $10{\cdot}437$, and $13{\cdot}569$, β being $\dfrac{V \sin \theta}{c}$, V the equatorial velocity and θ the inclination of the axis to the line of sight. If a line yields these zeros it does not follow inevitably that it must have been rotationally broadened, but that this has happened becomes very likely. The chief question is as to how far these methods in application are affected by observational errors. In his discussion of this point, Carroll shows that some of the observational distortions which may be expected will leave undisturbed the zeros to which reference has just been made, so that in one sense at least these errors do not affect the velocity determination, although, on the other hand, they can in unfavourable cases make the determination impossible by the introduction of superfluous zeros. If the original unbroadened line profile is required, the whole of the observational errors affect the result. Carroll says: "For satisfactory computations very much greater accuracy in the absolute values of line profiles is needed than appears usual at the moment." The quotation is important in view of the fact that a number of his readers, to the present writer's knowledge, have been tempted to conclude that the mathematical analysis is now sufficiently powerful to produce the required results almost irrespective of observational errors.

In stars which are rotating rapidly there may be a sufficiently great reduction of surface gravity in the equatorial regions to affect atomic ionization and hence the conditions of line formation. Swings and Chandrasekhar ‡ have worked out the effect on line profiles in a number of particular cases.

* *Ap. J.*, **79**, 357, 1934. † *M.N.*, **93**, 478, 680, 1933. ‡ *M.N.*, **96**, 883, 1936.

Interferometer Measures of Narrow Bright Lines.—A Fabry-Perot interferometer may be used for measuring the profiles of bright lines too narrow to be dealt with successfully by an ordinary spectrograph. There have been two important applications which may be noted here.

At the 1932 total solar eclipse, Shane * obtained with a Fabry-Perot interferometer a photograph of the spectrum of the corona. The well-known green line showed no interference fringes, although a comparison spectrum demonstrated that the instrument was in good adjustment. It was deduced that the line must be at least 1/3 A. wide.

The galactic nebulæ form another source of comparatively narrow emission lines. In a classical research, more than twenty years ago, Fabry and Buisson showed that the then unknown substance producing the nebulium lines should have an atomic weight 3. They obtained this result by measuring the relative widths of the hydrogen and nebulium lines in the Orion nebula and by assuming that the sole source of line broadening is Doppler effect from the thermal motions of the atoms. Four or five years ago similar measures were made by Baade, Goos, Koch and Minkowski,† using improved instrumental arrangements, and their results agreed very closely with those of Fabry and Buisson. As we know now, the source of the nebulium lines is oxygen and the question arises as to why they are wider than expected, relative to the hydrogen lines. The most likely explanation is that there are macroscopic motions of the nebula in the line of sight as well as the microscopic thermal motions of individual atoms. There is a certain amount of observational support for this suggestion.

Miscellaneous Investigations.—(*a*) Variation of Fraunhofer line profiles in the solar spectrum.

It is unfortunate that no long series of calibrated photographs are yet available to give a reliable test of this important problem. Shorter series and also fairly long series of uncalibrated plates have been examined by a number of investigators (Minnaert, Bleeker and van der Meer,‡ van der Meer, § Kharadse ‖). Changes, if present, must be quite small, and it is significant that as the method of measurement improves the apparent variations diminish.

(*b*) Line profiles in sunspot spectra.

Thackeray ¶ finds that lines over a sunspot generally have higher central intensities than over the disc, while rare-earth lines are noticeably diffuse in spot and limb spectra. Incomplete observations made at Cambridge by the present writer suggest that in some of the strong metallic lines the central intensity over a spot is very little different from that over the disc.

(*c*) Reflection effect in spectroscopic binaries.

If the inner face of a rotating component of a spectroscopic binary is made brighter, without change of spectrum, by reflection from the other component, the observed spectrum lines will at some phases be asym-

* *P.A.S.P.*, **44**, 358, 1932.
† *Z. f. Ap.*, **6**, 355, 1933 ; **9**, 202, 1934.
‡ *Z. f. Ap.*, **8**, 59, 1934.
§ *Z. f. Ap.*, **13**, 157, 1937.
‖ *Z. f. Ap.*, **10**, 339, 1935.
¶ *P.A.S.P.*, **48**, 119, 1936.

metrical, to an extent which might be measurable.* The effect, however, may be concealed by other causes of asymmetry.†

Struve ‡ has brought forward evidence to show that in α Virginis the reflection is not diffuse in nature, but is responsible for forming its own absorption line in the spectrum of the secondary. This view is held to be in agreement with theory.

2

Observational Technique §

Instruments.—We determine the profile of an absorption line by measuring its image in the focal plane of a spectrograph, usually, but not invariably, by means of photography. The errors of the result depend on how true a representation of the line is the image, as well as on how accurately we can measure the light distribution in the focal plane. As far as spectrographs are concerned, the paramount need in this kind of work is for high resolving power, for the lack of which our investigations are continually being restricted, in solar work almost as much as in stellar investigations.

(a) *Solar Spectrographs.*—When observing the Sun, economy of light is no object and the largest and most powerful spectrographic apparatus may be used. For accurate profile measurement a line has not merely to be resolved from its fellows, but it must also be depicted by the instrument with relatively little distortion. In this respect existing instruments are inadequate to deal with lines fainter than about Rowland number 5, *i.e.* of equivalent width about 1/6 A. (the working limit depending on the accuracy sought), so that at present we are able to measure with moderate precision the profiles of only a minority of the known lines in the solar spectrum.

The optical performance of a spectrograph is accurately assessed only when we can determine the instrumental profile, *i.e.* the distribution of light which would be observed in the focal plane were the slit to be illuminated with perfectly monochromatic light. It is customary to describe an instrument's properties by its theoretical resolving power, but there are two reasons why this is inadequate for profile work. First, the resolving power is really only a rough description of the inner part of the instrumental profile, the core which controls the ability of the instrument to distinguish near-by spectrum lines from each other, whereas in the work we are considering the outer parts are also very important. Secondly, no instrument gives theoretical performance in practice, even after allowing for finite slit width, and this is specially true of the outer parts of the instrumental profile, which are generally a good deal stronger than theory predicts. However, for lack of any other compact description we will speak in terms of resolving power and note that the largest diffraction gratings have in the first order

* McCarthy, *Ap. J.*, **82**, 261, 1935.

† Struve and Ebbighausen, *Ap. J.*, **80**, 365, 1934.

‡ *Ap. J.*, **86**, 198, 1937.

§ General references: Ornstein, Moll and Burger, *Objektive Spektralphotometrie*, 1932; Plaskett, *Trans. I.A.U.*, **5**, 239, 1935.

a resolving power about 100,000. The third order should give 300,000, but both these figures overestimate the usefulness of an ordinary good grating for profile work, on account of ghosts and "false light" scattered or diffracted into the outer parts of the instrumental profile. The best glass-prism trains in use give an effective resolving power about 100,000 in the violet (although this may be considerably exceeded in the near future), and yield spectra with much less false light than do gratings. But in contrast to this we are in urgent need of a real resolving power 10^6, for even the strong metallic lines in the solar spectrum are appreciably distorted at their centres by our best instruments.

There have been marked improvements of recent years in the manufacture of diffraction gratings,* largely owing to the fact that the rulings may now be made in a comparatively soft aluminium surface deposited on a suitable support by evaporation instead of in the tough speculum formerly used. Nevertheless, there is no immediate prospect of successful rulings being made with 10^6 lines. Similarly, while the technique of manufacture of optical glass has made considerable strides in the past twenty years, and it is now possible to obtain prisms more transparent and more homogeneous than ever before, the upper limit to the aperture still stands at about 15 cm., so that the chances of attaining resolving power 10^6 seem as small for a train of flint-glass prisms as for a diffraction grating.

Increased resolving power should be obtainable by the use of liquid prisms, since they commonly have about twice the dispersive power of flint glass. The primary difficulty, excessive sensitivity to temperature variations, may be countered by the use of a precision thermostat, for which a number of designs are now available.† Granted that the necessary precision in temperature control could be achieved, it is possible that larger apertures could be used than with glass. There remains the objection that some of the liquids employed in prisms (*e.g.* carbon disulphide) scatter more light than does good optical glass,‡ but here, and indeed in the whole matter of liquid prisms, there seems room for further investigation, while the use of a monochromator before the main spectrograph would very much reduce the effect of the scattered light on the spectrum.

If prisms and gratings do not offer enough scope for increased resolution, the only alternative left is some form of interferometer. These are on the whole not so well adapted for work on Fraunhofer lines as on the emission spectra usually being investigated in the laboratory, but Shane § has developed a method for measuring profiles using a Fabry-Perot étalon, while Carroll || has employed an echelon grating for studying the chromospheric spectrum at a total solar eclipse. Further experience is greatly needed in the employment of both of these types of interferometer for line profile work.

Stellar Spectrographs.—The need for high resolving power is no less

* *E.g.* Wood, *Nature*, **140**, 723, 1937.
† Turner, *Journal of the Institution of Electrical Engineers*, **81**, 399, 1937.
‡ Woolley, *Observatory*, **58**, 337, 1935.
§ *Lick Obs. Bull.*, **16**, 76, 1932.
|| *Nature*, **138**, 349, 1936.

acute when dealing with stellar spectra than in the case of the Sun. The majority of stellar spectrographs have far less effective resolving power than have the bigger solar instruments, although the discrepancy is being reduced by the use of stationary coudé instruments. On the whole, however, we have to be content with a much more modest standard of performance in stellar than in solar work, so that attention has been directed chiefly to measuring only the strongest and widest lines to be found.

The cardinal virtues of a stellar spectrograph, besides the greatest possible resolving power, are speed and (unless it is a coudé instrument) mechanical rigidity. Owing to the fact that with the large telescope apertures necessary for spectrographic work "seeing" imperfections generally make the star image a great deal larger than the Airy disc, so that it has effectively the appearance of a small nebula, speed in the spectrograph can be increased to a limited extent, without sacrificing resolution, by increasing the angular dispersion of the optical train, shortening the camera and increasing the slit width. The success with which this policy can be followed depends on the production of more transparent prisms or more efficient gratings, and here, as we have already seen, marked improvements have been made of late years. It also depends on the manufacture of more efficient camera objectives. With these, the most important recent advance has been the introduction of Schmidt mirrors, which give very fast cameras transparent to the ultra-violet and with a satisfactorily wide field of good definition. The most noteworthy applications have been at Mt. Wilson, particularly by Dunham to the 100-inch reflector coudé spectrograph.*

It is essential to remember that a stellar spectrograph in practice rarely approaches its theoretical performance for zero slit width. In the first place the slit is used at relatively great widths, and in the second no photographic dry plate can resolve more than 160 lines per mm., this standard being attained only with plates so slow as to be practically useless for stellar work. Fast and moderate speed plates resolve 30 to 70 lines per mm., so that with the relative apertures normally employed in the cameras of stellar spectrographs, theoretical performance is in any case prohibited by plate grain. Spectrographs carried on telescopes must always show a certain amount of mechanical flexure as their orientation varies, since no known material is perfectly rigid. In a well-designed instrument the flexure should be negligibly small, but it is frequently greater than it should be, and the accuracy of determination of line profiles must then suffer.

Light-sensitive Receivers.—There is little likelihood that the photographic plate will in the near future be displaced from its position as the most convenient light receiver in astronomical spectroscopy. Apart from high sensitivity, the wide range of wave-length over which it can work, comparative cheapness and ease of manipulation, its outstanding advantage is an ability to record simultaneously the whole of the radiation in an extended range of spectrum. In this last respect it is immensely superior to all rivals. Nevertheless, it should not be concluded that other light receivers are without their uses. Apart from all other considerations, it is very

* *Mount Wilson Observatory Annual Reports*, 1933–37.

desirable to have an independent check on the systematic errors of photographic work. Leaving until the next section questions relating to the photographic method, we will here mention briefly the possibilities of the human eye and of the photocell.

Of late years the eye has been rather unfashionable as a scientific instrument, particularly for photometry. It is, however, sufficiently sensitive for observing the solar spectrum, and its advantages for the study of transient phenomena or for work in the green part of the spectrum have been described by Minnaert.* Line profiles and intensities in $H\alpha$ have been determined visually with a spectrohelioscope by Woolley and Newton,† who worked on various characteristic features of the Sun, prominences, dark markings, etc.

The photocell has two outstanding advantages as a light receiver. In arrangements giving relatively low sensitivity it is capable of yielding measurements of very great accuracy, such as can be obtained by photography only in long series of observations. Or it may be used in other ways, with a Hoffmann electrometer, a suitable thermionic amplifier and galvanometer, or combined with a Geiger-Müller counter, to give extremely high sensitivity, still with considerable accuracy. The combination of a photocell and counter ‡ in one unit is often termed a "photon counter", although this is a misnomer, as the output at best is only about 1 electron per 500 photons. The sensitivity attained is nevertheless very high and necessitates the greatest care on the part of the observer. In a number of cases publications have announced, on the basis of "photon counter" observations, the detection of faint radiation later shown to be non-existent. (One may instance the notorious mitogenetic rays in biology.)

The only application of photocells to the measurement of line profiles which so far has been announced was made by Dunham,§ who finds that he can readily obtain an accuracy within 1 per cent. of the continuous background.

Photographic Photometry.—Photographic emulsions of better quality than ever before are now available for astrophysical research. This is due mainly to two facts: (*a*) manufacturers such as the Eastman Kodak Company || and the Ilford Company ¶ are now prepared to make special plates for scientific purposes, ensuring that the purchaser obtains an emulsion as nearly suited to his needs as is humanly possible, (*b*) there has been an enormous extension of sensitivity to the infra-red as the result of introducing new sensitizing dyes. In the ordinary blue to near ultra-violet region, however, there has been little change of note in plate characteristics. Plate grain and irregular sensitivity from area to area of the emulsion are still

* *Z. f. Ap.*, **4**, 358, 1932.

† *M.N.*, **96**, 5, 1935; **97**, 531, 1937.

‡ For a general description see Audubert, *J. de Physique et le Radium*, **6**, 451, 1935.

§ *Physical Review*, **44**, 329, 1933.

|| Mees, *Photographic Plates for Use in Spectroscopy and Astronomy*, 3rd Edition, 1937.

¶ *Journal of Scientific Instruments*, **12**, 333, 1935.

two of the major sources of inaccuracy in photographic photometry. In general, as the speed of a photographic emulsion increases there is a parallel increase of graininess, large-scale irregularities in sensitivity, and liability to chemical fog, while there is a decrease in the contrastiness of the image and the keeping properties of the plate. It is therefore a good rule always to use the slowest emulsion that one conveniently can.

With regard to grain, there is an upper limit to the amount of improvement which can be made, since one cannot produce more independent developable silver grains than the number of light quanta which have struck the plate during exposure. At present something of the order of 100, or rather less, quanta are required for each grain, and there seems no great likelihood of this figure being radically altered in the near future. If the number of grains cannot be increased, their average size cannot be diminished without reducing the density of the silver deposit, and the most that we can hope for is that they should be made of a more uniform size and more uniformly spaced.

The irregularities of larger scale are generally attributed to variations in the thickness of the emulsion and in the rate of drying during manufacture. It has been suggested by Mees that astronomers would find films better than plates in this respect, owing to the methods by which they are coated and dried. Unfortunately, however, current methods of measurement of the photographic image, both for position and density, are much better adapted to plates, so that in general films give less accurate results.

The speed of fast plates still shows rather disconcerting variations from batch to batch, while a decrease with age is always encountered, sometimes preceded by a short-lived increase. The deterioration with age is a chemical action which accelerates as the temperature rises, and Mees, in consequence, recommends a refrigerator for storage. This precaution is essential for infra-red or fast panchromatic plates.

With regard to development, it is of considerable advantage to use some form of thermostat and conduct the process always at the same temperature, which should be within the range 15° to 20° C. Mees recommends 18° C., while some workers prefer 15° C., maintaining that Eberhard effect is then less troublesome. The so-called fine-grain developers which have come into prominence of recent years may be found of value,* but their suitability for photometric work needs further examination. Since the mode of action of many, if not all, of these developers is to dissolve away a part of the image and to give less photographic density and contrast, their use is liable to lead to disappointment when the results are judged by microphotometer tracings. It is generally considered that some agitating device for the developer is most desirable, principally for the reduction of Eberhard effect. A soft brush is the simplest example and as satisfactory as many more complicated arrangements. Development should always be carried out in complete darkness, whatever the nature of the plate, as a red lamp can influence the image in other ways than by mere fogging (Herschel effect). Eberhard effect continues to be a nuisance and the position with

* Morgan, *Ap. J.*, **83**, 254, 1936.

regard to it is still far from clear. Such apparently contradictory evidence is produced on the subject that one can only suppose that the effect depends on quite a number of different parameters, among them probably the plate emulsion, the speed and length of development, as well as the composition of the developer and the degree to which it has been agitated. It is possible that the range of density at which measurements are made has also an influence in the matter. The most that each worker can do at present is to test his own methods and apply any correction to his results that appears necessary.

For a photographic plate the relation between density and light intensity, the characteristic curve, may vary with wave-length, time of exposure, intermittency of light source, and the interval between exposure and development, as well as on the particular emulsion and the process of development. It may also vary between one point of the plate and another, as mentioned above, but this has usually to be endured as an inevitable source of error. For maximum accuracy, however, the factors just enumerated should be kept constant between the spectrum exposure and such supplementary exposures which have been necessary to determine the characteristic curve. The need for this was recognized and expressed by Hartmann nearly forty years ago—and too often overlooked since. It cannot be too strongly emphasized that, despite our much greater knowledge to-day concerning the photographic plate, an investigator still neglects these precautions at his peril, and in so far as his experimental necessities force him into deviations from Hartmann's criterion, he should test the effect of his procedure on his particular photographic material. Plates differ so much in their properties that because a certain method can be used with one kind, it by no means follows that it can be employed with impunity with others. For example, one may take advantage of the fact that the characteristic curve of some slow blue-sensitive plates (*e.g.* Ilford Process) changes very slowly indeed with exposure time, but the same liberties cannot be taken with some fast, colour-sensitive plates if the same degree of accuracy is to be maintained, since with them there is a much more rapid change of characteristic curve with exposure time.

Microphotometers.—If photographic photometry is to be used, it is necessary to have an instrument which will give accurately and quickly a record on some arbitrary scale of the density on a photographic plate. Individual requirements are so diverse that many astronomers and physicists prefer to build their own microphotometers rather than rely on one of the standard types now marketed, so that a rich variety of designs is to be found in many publications. Three good examples, intended specially for astronomical work, have been described in the *Monthly Notices*.*

It is important to notice that different machines have markedly varying properties with regard to the range of plate density over which they work best. Few, if any, give readings proportional to photographic density as it is strictly defined. For instance, those using the Koch arrangement of

* Carroll and Moss, *M.N.*, **91**, 191, 1931; Plaskett, *M.N.*, **95**, 160, 1934; Beals, *M.N.*, **96**, 730, 1936.

two photocells, one acting as a compensator, work best at low plate densities ; the photocell and amplifier described by Beals works best at higher plate densities ; machines with a vacuum thermocouple and galvanometer lie between these two. To work always at low densities is not an unmixed advantage ; exposure times are somewhat shortened, but the effect of irregularities of any kind in the plate, and especially of plate grain, becomes more pronounced.

The process of measuring microphotometer tracings and reducing the plate densities to light intensities is very time-consuming, and a number of ingenious devices have been made to shorten the labour.* It is to be remarked that the invention of a microphotometer producing a tracing directly in terms of intensity or log (intensity) is not a matter of insuperable difficulty, although such a machine would probably be considerably more expensive than those of conventional design.

Spectrograph Performance.—The image of a spectrum line produced in the focal plane of a spectrograph is always more or less distorted. If the true line profile is $L(x)$, x being a co-ordinate measuring position in the spectrum image parallel to the dispersion, and $I(x)$ is the instrumental profile, the observed profile will be

$$O(x) = \frac{\int_{-\infty}^{+\infty} L(x) \,.\, I(x-\xi) \,.\, d\xi}{\int_{-\infty}^{+\infty} I(\xi) d\xi}.$$

If we know $O(x)$ and $I(x)$, we can readily deduce $L(x)$ numerically by a series of successive approximations, provided the difference between $O(x)$ and $L(x)$ is fairly small, *i.e.* provided the instrumental distortion has not been too great.

For precision it is not sufficient to calculate the theoretical $I(x)$; it must be measured directly. This can be done in two ways : (i) we use a laboratory source giving emission lines which we know from other evidence to be very much narrower than the instrumental profile. Unsöld † suggested this method some years ago, and it has been applied more recently by Allen and by Redman. The source needs to be selected according to the capabilities of the spectrograph under examination ; for very high resolving power the krypton discharge tube is probably best, at least in the violet. Neon line have been used in the red, but the theoretical width of these lines is greater than for krypton, while there is also a displaced isotopic component present. Allen ‡ has found evidence that these lines are somewhat wider than theory predicts. (ii) An alternative is to use absorption lines of known structure and from their measured shapes deduce the instrumental distortion. If the measuring programme is directed towards absorption lines this is more satisfactory than (i), but the difficulty is to find suitable lines. For the red and near infra-red, Allen has used with good results the components of the

* *E.g.* Dunham, *Publ. Am. Ast. Soc.*, **7**, 215, 1933 ; Perepelkin, *Comptes Rendues U.S.S.R.*, **15**, 25, 1937.

† *Ap. J.*, **75**, 106, 1932.

‡ *Ap. J.*, **85**, 165, 1937.

B and A bands of molecular oxygen, whose origin is in the Earth's atmosphere and whose shapes can be computed with a fair degree of certainty.

In addition to being thoroughly acquainted with the optical properties of his spectrograph, an observer should know how much scattered light is present in the instrument. This is particularly important with the Sun, where a longer slit is used than in stellar work. Observers frequently overlook the fact that the amount of scattered light will increase directly as the amount of light admitted to the spectrograph and in solar work tend to use the slit quite unnecessarily long. The ideal arrangement is to work with a monochromator before the main spectrograph, as was first done by Dunham,* and later by Thackeray † and Redman.‡ Measures made at Cambridge have shown, however, that unless one is working in a region strongly affected by instrumental or atmospheric absorption, or low spectrum sensitivity of the plate, scattered light may be reduced to less than 0·5 per cent. of the continuous spectrum by cutting down the slit length to 1 mm., an amount which is still ample for all profile measures. This result was obtained with a fairly well-diaphragmed prism spectrograph in a Littrow mounting. With a grating spectrograph a monochromator cannot be so easily dispensed with, since false light scattered and diffracted by the rulings is generally much stronger on the plate than that scattered and reflected by a prism train.

The method developed by Shane and already referred to removes some of the worst effects of scattered light and instrumental distortion, since he measures his profile in the light of the maxima in Fabry-Perot fringes, while the false light is derived from the integrated effect over the whole fringe system and is thus relatively weaker. He also is able to deduce his instrumental profile, provided its general form is known, from measurement of the maximum to minimum ratio in the fringes. His method, however, suffers from the disadvantage that measures have to be made on rather narrow fringe maxima, which are more readily disturbed by plate irregularities than the smoother density distribution in an ordinary spectrogram, while also it is necessary to give rather long exposures when the étalon is in position. §

Scattered Light in the Sky and Telescope.—False light is encountered not merely in the spectrograph image but also in the image on the slit, arising from scatter in the earth's atmosphere and in the telescope. For ordinary stellar work and for observation at the centre of the Sun's disc this particular trouble is of no importance, but in studying light from near the limb or from specific features on the solar surface, such as sunspots, a certain amount of difficulty may be encountered. To some extent one may effect improvement by observing only in the best sky conditions and by keeping the mirrors or lenses of the telescope train in the best possible condition, but for accuracy it is necessary to measure the scattered light that

* *Mount Wilson Annual Report*, 194, 1930–31.
† *M.N.*, **95**, 293, 1935.
‡ *M.N.*, **95**, 290, 742 ; **97**, 552, 1937.
§ Cherrington, *L.O.B.*, **17**, 161, 1935.

remains and apply corrections by some method such as that described by Wanders.*

Wing Profiles.—Granted that we have avoided systematic errors arising from poor photometric methods, Eberhard effect, instrumental distortion and scattered light, there may still be difficulty in fixing the position of the continuous background and of making sure of the course of the line wings, where the intensity gradient is very small. The rather big differences of integrated line intensities which are persistently found between different observers of the solar spectrum † is often put down to this cause, which seems on the whole a more likely explanation than that there are real variations in the lines.‡ The point has been discussed by Minnaert,§ who shows how easy it is to under-estimate the extent of the wings and in consequence to produce integrated line intensities which are too small. He finds it best to follow the wing by the aid of theoretically predicted profiles, and provides a striking example in the K line of the solar spectrum, the wings of which have to be measured over a region twenty times the equivalent width of the line in order to reduce the error in the integrated intensity to 2 per cent.

R. O. REDMAN.

* *Z. f. Ap.*, **8**, 108, 1934.
† Woolley, *Observatory*, **58**, 329, 1935.
‡ E. T. R. Williams, *Ap. J.*, **72**, 127, 1930.
§ *Z. f. Ap.*, **10**, 40, 1935.

(The Present Note covers the Three Years 1935–37)

The Nature of the Spectral Displacements towards the Red

It is some years now since the question was first raised as to whether the spectral shifts towards the red in distant spiral and elliptical systems should be interpreted in the ordinary way as measures of recession, or whether they indicate a different and unknown effect on light itself whilst traversing vast distances over long periods of time.

In 1929 F. Zwicky (*Pro. Nat. Acad. Sci.*, **15**, 773) considered various theoretical possibilities to account for the phenomenon, and ultimately suggested that there might be a gravitational "drag" on light quanta. According to the relativity theory a light quantum has an inertial and gravitational mass: it should be expected therefore that a quantum h passing a mass M will not only be deflected, but will transfer momentum and energy to the mass M and make it recoil. During this process the light quantum (or photon) will change its energy and therefore its frequency.

Zwicky suggested that this effect should be apparent in the globular clusters, which are appendages to the galactic system. This was investigated by ten Bruggencate in *Pro. Nat. Acad. Sci.*, **16**, 111, 1930, who found that there exists a linear correlation in the displacements of spectral lines for globular clusters, corrected for solar motion and galactic latitude, similar to the correlation between line displacement and distance which holds for the spiral nebulæ.

Hubble and Humason in 1931, after expressing their belief that their magnitude scale of the fainter nebulæ was well established, and that apparent magnitudes may be accepted as measures of distance for the various types, conclude by saying: "The interpretation of red shifts as actual velocities, however, does not command the same confidence, and the term 'velocity' is used in the sense of 'apparent velocity' without prejudice to its ultimate significance" (*Mt. Wilson Cont.*, 427).

In 1932 Prof. W. D. MacMillan in a letter to *Nature* of January 16 suggested that the red shift may be owing to loss of energy in the photon in course of time, due either to an inherent instability of the photon, or possibly to collisions with other photons. In such a case, loss of energy would be equivalent to a decline of frequency.

Any observational method which would distinguish between the two interpretations would obviously be of fundamental importance. Two theoretically possible methods have been suggested; these depend on the relations connecting either nebular angular dimensions or nebular counts with observed luminosities, which might be expected to hold under the alternate hypotheses. The two methods are discussed by Hubble and

R. C. Tolman in *Mt. Wilson Cont.*, 527 (1935). Both of them are difficult to apply in view of such factors as the indefinite outer limits of nebular angular diameters, the necessity for relating apparent bolometric luminosities to observed photographic magnitudes, and the effect on nebular counts produced by a wide spread in the actual values of absolute nebular magnitudes. Part I of the paper deals with relations which might be expected to hold in case the red shifts are due to recession. In this case the universe is represented by a homogeneous expanding model obeying the relativistic laws of gravitation. By the assignment of suitable values to the different parameters involved in the equations a wide variety of special cases becomes available for comparison with observation. One of these special cases leads to important observational properties, which are approximately the same as would be predicted from Milne's kinematic model.

Part II of the paper presents similar relations if it is assumed that the red shift is due to some other cause than recession. In this case the model adopted is the static Einstein universe, combined with the assumption that the photons emitted by a nebula lose energy on their journey to the observer by some unknown effect which is linear with distance and leads to a decrease in frequency, but to no decrease in the *rate* of arrival.

It is extremely doubtful, not to say improbable, if any adopted system of mechanics would allow of the existence of a stable static distribution of nebulæ, and the only reason why Einstein's static model has been used is that it is a limiting case in which the effect of expansion or contraction would be negligible compared with the assumed unknown cause of the red shift. The rest of the paper is devoted to a theoretical discussion as to the observational possibilities of the two methods—a comparison between angular diameters and bolometric luminosities or counts and photographic luminosities. The first of these is not yet available with our present observational knowledge, although such a method has advantages, since the results of such a test should be less dependent on the assumed homogeneity of the model than those dependent on nebular counts; the second is a possibility with the observational material of faint nebulæ from 19 to 21 integrated mag. now available from Mt. Wilson.

Another important matter is the type of spectrum of the nebulæ. With a few exceptions, the spectral type found in the nebulæ is F- to G-type, and the assumption is usually made that the nebular spectrum is comparable through its range with F- and G-type stars, with a temperature of about 6000° C., on the further assumption that the black-body radiation law holds. In the nebulæ the line absorption is presumably comparable with that in the Sun, but the distribution of continuous radiation is modified by an observed colour excess of about 0·15 mag. The source of the excess is unknown, but it will clearly reduce the equivalent black-body radiation.

These and other basic considerations are dealt with fully in a paper by Hubble, "Effects of Red Shifts on the Distribution of Nebulæ" (*Mt. Wilson Cont.*, 557, 1936). This is an extension of his paper, "The Distribution of the Extra-galactic Nebulæ" (*Mt. Wilson Cont.*, 485, 1934), in which the distribution is considered to a limiting integrated photographic

magnitude of 21. The fresh material now available consists of two groups, the first containing 41 fields, with the 100-inch reflector, the exposures ranging from 100 min. to 150 min., the second containing 40 fields with the 60-inch reflector, all the exposures being 20 min.

The limiting magnitude of the 20-min. exposures with the 60-inch reflector was measured from "schraffierkassette" images as 19·0 or 19·2, and the mean value, $18{\cdot}47 \pm 0{\cdot}03$, is believed to be reliable except for the uncertainties in the scale of comparison stars and in the zero point in the scale of nebular magnitudes.

The results from the 100-inch exposures after careful calibration take the limiting magnitude down to 21.

From these data the number of nebulæ per square degree, N, to limiting magnitudes m are found to be represented by the relation

$$\log N = 0{\cdot}6\,(m - \Delta m) - 9{\cdot}052 \pm 0{\cdot}005 \qquad (1)$$

in which the corrections Δm are represented as apparent departures from large-scale uniform distribution, and are interpreted as due to the modifications in apparent luminosities resulting from the displacement of the spectrum towards the red.

Since it is assumed that the red shifts $d\lambda/\lambda$ and the corrections Δm are both approximately linear functions of distance over the observed range, one can be expressed as a linear function of the other. The velocity-magnitude relation has been found to be (*Mt. Wilson Cont.*, 549)

$$\log v = 0{\cdot}2(m - \Delta m) + 0{\cdot}77, \qquad (2)$$

or

$$\log \frac{d\lambda}{\lambda} = 0{\cdot}2(m - \Delta m) - 4{\cdot}707, \qquad (3)$$

and

$$\log \Delta m = 0{\cdot}2(m - \Delta m) - 4{\cdot}239, \qquad (4)$$

hence

$$\Delta m = 2{\cdot}94 \frac{d\lambda}{\lambda}. \qquad (5)$$

The apparent luminosity of a nebula is measured by the rate at which its light quanta reached the observer, and by the energy in the quanta. The effect of red shifts on these quantities gives rise to what Hubble terms "number effect" and "energy effect" respectively. Recession includes both effects, but loss of photon energy produces only "energy effect." Perhaps the simplest way of explaining the difference in action between "number effect" and "energy effect" on the spectrum is to say that "number effect" operates on all wave-lengths equally and reduces the whole vertical energy scale of the spectrum; whereas "energy effect" is selective along the horizontal wave-length scale, pushing the whole spectrum in the direction of longer wave-lengths, and at the same time decreasing the vertical energy scale selectively.

With (5) as the definite result of the observational investigation it is of

importance to compare it with theoretical amounts calculated (*a*) on the assumption that the magnitude corrections are due to recession ("number effect" plus "energy effect"), and (*b*) to loss of photon energy ("energy effect" alone).

Number Effect.—Since this is non-selective, the apparent magnitudes would be increased by the same amount all along the spectrum, namely

$$\Delta m_N = 2{\cdot}5 \log \left(1 + \frac{v}{c}\right).$$

In expanding models of the universe obeying the relativistic law of gravitation, the ratio v/c is replaced by $d\lambda/\lambda$.

Energy Effect.—The energy effect is selective, for it changes the horizontal or wave-length scale of the energy-distribution curves. Bolometric magnitudes are increased by the increment

$$\Delta m_E = 2{\cdot}5 \log (1 + d\lambda/\lambda).$$

To express bolometric magnitudes as the observed photographic magnitudes, it is necessary to take into account the atmosphere (selective absorption), the telescope (selective reflection) and the type of photographic plate used (selective sensitivity). These are included in a K term. Then the total effect of red shift on apparent photographic magnitude is to increase the magnitude by the increment

$$\Delta m = 5 \log \left(1 + \frac{d\lambda}{\lambda}\right) + K$$

if the red shift is a recession effect, or

$$\Delta m = 2{\cdot}5 \log \left(1 + \frac{d\lambda}{\lambda}\right) + K$$

if it is a photon energy reduction effect.

A value of K having been discussed and approximately determined, the next step is to apply the correction. The energy effect Δm_{E} is then found to be related with $d\lambda/\lambda$ by a probable factor B of 3.

On the other hand, this factor, if a simple recession effect, is calculated to be $B = 4$, and as the observed factor derived is 2·94, Hubble concludes that, provided the Einstein static universe model adopted has a negligible curvature, the observations are consistent only with the hypothesis that the red shift is not a velocity effect but a decreased photon energy effect, or some analogous cause. This is, of course, a conclusion of fundamental importance from the cosmological point of view, and alters entirely the conception of the expanding universe, if it is substantiated.

Sir Arthur Eddington in *M.N.*, **97**, 156, draws attention to the dispersion in the distance of the nebulæ, and to the point that the corresponding dispersion of Δm will scatter nebulæ of any particular magnitude through a considerable range of corrected magnitudes. It is not at all obvious that this will have the same effect on statistics as the application of a mean

correction $\overline{\Delta m}$. He therefore applies a rigorous statistical treatment which takes into account the dispersion of the absolute magnitudes of the nebulæ.

This proved unexpectedly to be a comparatively simple matter. From an observed frequency $N(m)$ it is possible to deduce the true frequency $N'(m)$, corrected for the effects of accidental error in determining m. By a mathematically identical process it is possible to remove the dispersion in absolute magnitude, and to deduce from the observed statistics $N'(m)$, representing the counts which would have been obtained if the nebulæ had all the same absolute magnitude. Adopting Hubble's determination of the dispersion $\sigma = 0{\cdot}85$, Eddington finds $\Delta m = 3{\cdot}06\ d\lambda/\lambda$ in place of Hubble's result $\Delta m = 2{\cdot}94 d\lambda/\lambda$. The difference is too small to be of importance, and therefore appears to be not inconsistent with Hubble's conclusion.

But Eddington points out that there may be other possible sources of accidental errors. For example, taking Hubble's estimate of the probable accidental error of m as $\pm\ {\cdot}03$, this corresponds to $\pm\ {\cdot}56$ in the factor B, and the discordance (3·06 against 4·0) is equivalent to a discordance of 0·066 mag. in the range of measured m.

Hubble replies to Eddington's criticisms in *M.N.*, **97**, 506, "Red Shifts and the Distribution of Nebulæ."

He first of all deals with the dispersion of Δm with distance and claims that this had been adequately considered in the original paper on the subject by R. C. Tolman and himself (*loc. cit.*), and in any case the difference between his result and Eddington's is not of any great importance. But Eddington's more serious criticism was directed to the small range of δm (18·47 to 21·03). He states that an error of 0·01 mag. in δm will produce an equal error in $\delta(\Delta m)$ and an error of 0·13 in B.

Hubble admits that the criticism is justified to a certain extent, and agrees that an increase in the range of δm would improve the situation. The only other published survey is the Harvard catalogue of the brighter nebulæ complete to $m = 12{\cdot}8$ (*Harvard Annals*, **88**, 2). If these data are included he finds the constants are essentially unchanged, but the weights are considerably increased.

However, systematic errors are more to be considered in the investigation than probable errors, and as soon as it had become evident that the factor B would fall below the expected recession value of 4·0 the observations were reduced by methods which at each step favoured a larger rather than a smaller value. He concludes his reply to Eddington by saying: "The interpretation of red shifts by the theory of expanding universes is so plausible and so widely current that in making a delicate test of the theory it is desirable to push uncertainties in the favourable direction before admitting a discordance. Nevertheless—and this is perhaps the significant result of the investigation—when the observational data are weighted in favour of the theory as heavily as can reasonably be allowed, they still fall short of expectations." This seems to sum up the results of the investigation fairly if we admit that the assumptions made in it are valid. In any case it must not be taken for granted that the red shifts are to be interpreted necessarily as measures of recession.

Relativistic Models of the Extra-galactic Universe.

Another criticism of Hubble and Tolman's papers is that of G. C. McVittie, "On the Distribution of Extra-galactic Nebulæ" (*M.N.*, **97**, 163, 1907). In these papers Hubble and Tolman arrived at the conclusion that if the red shifts are velocity shifts space has a positive radius of curvature of the order of $4{\cdot}7 \times 10^8$ light-years, and that the average density of matter is of the order of 10^{-26} gr./cm.^{3}.

McVittie is concerned with the application of the formula

$$\log \delta = 0{\cdot}2m - 4{\cdot}967$$

(where δ is the actual Doppler shift, and the value is arrived at by considering magnitudes down to 17 only) to the formula

$$\log N = 0{\cdot}501m - 7{\cdot}371,$$

which is the empirical formula given by Hubble for the number of nebulæ to the limiting photographic magnitude m within the range 18·47 to 21·03 m. It was necessary to extrapolate the first formula in order to make it consistent with the second, and McVittie suggests that Hubble's extrapolation, in which the first equation is modified, is not correct, and that the extrapolation should be made without modification. McVittie comes to the conclusion that the counts $\log N$ are in agreement with an infinite universe of *negative* curvature, the radius of which is of the order of 10^9 light-years, the average density of matter being of the order of 10^{-32} gr./cm.^{3}; the cosmical constant has a value of -21×10^{-34} sec.$^{-2}$, and the expansion is being retarded.

Hubble replies to this criticism in the latter part of his paper in *M.N.*, **97**, 506, 1937. He points out that McVittie has by an oversight compared coefficients in two equations which do not contain comparable data, consequently McVittie's value of the density ρ must be revised to $6{\cdot}7 \times 10^{-28}$ gr./cm.^{3}: but other considerations reduce ρ to 10^{-28} gr./cm.^{3}. As this value is well below the critical value of $6{\cdot}85 \times 10^{-28}$ gr./cm.^{3} the derived curve is negative and the radius is of the order of 10^9 light-years, which Hubble considers to be anomalous. In a homogeneous expanding universe a negative curvature would introduce an apparent thinning out in the numbers of nebulæ with distance (after corrections have been applied for the dimming effects of red shifts); actually an apparently increasing distribution density is observed. Hubble therefore adopts a positive curvature.

If red shifts are not primarily velocity shifts, the observable region appears as a small, homogeneous, but insignificant sample of a universe which may extend indefinitely both in space and time.

Reference should be made here to a letter of McVittie which appeared in the *Observatory*, 1937 June, in which he suggests the adoption of a smaller mean mass for the nebulæ.

Perhaps the writer of this note may add that a great deal in these investigations depends on the meaning attached to the word "homogeneous." Is the knowledge we have of the actual distribution from near to very faint

and distant objects sufficient to make the assumption of approximate homogeneity? Is not the observed tendency towards clustering an essential and integral part of the question of distribution, and is it legitimate to average out these considerable irregularities?

In face of these difficulties, it seems that the results of such investigations, although important and of very great interest, must not be accepted as carrying any more weight than the assumptions which have necessarily to be made for mathematical treatment.

The Apparent Distribution of the Extra-galactic Nebulæ

This question has been frequently referred to in previous Council Notes on nebulæ. Our knowledge down to a limiting integrated magnitude of 13 is now fairly complete, owing principally to the photographic survey covering the whole sky contained in *H.A.*, **88**, 2, 1932. This includes all the spiral and irregular systems of angular diameter exceeding 3′, and the brighter elliptical systems. For fainter and smaller systems our information is still very restricted, and is limited to photographic investigations of particular regions. Hubble in *Mt. Wilson Cont.*, 485, 1934, has investigated the distribution of about 44,000 systems distributed over the whole sky north of $-30°$ Dec., the great majority of which are very faint and distant. In this survey 765 plates were utilized, and the plates were obtained with the 100-inch and 60-inch reflectors, 690 with exposures of one hour, 74 with half-hour exposures, and one with three-quarters of an hour. They were distributed so as to give something like uniformly spaced samples of distribution along circles of galactic latitude 5° apart, the galactic equator itself being omitted. In addition, a considerable number of extra survey plates were brought into the discussion to determine the limits of the irregular "zone of avoidance" in the regions centred along the galactic equator, and in two isolated patches of obscuration, one centred about $\lambda = 335° \beta = +35°$, the other about $\lambda = 145° \beta = -35°$. But even this elaborate investigation, which included 1283 independent samples embracing a total area of something like 650 square degrees, only covers a trifle more than 2 per cent. of three-quarters of the sky.

Then we have other discussions by Shapley, both of groups and of the general distribution, such as the 24-inch Bruce refractor results comprising about 100,000 nebulæ down to much fainter limits than the 13th integrated magnitude (*Proc. Nat. Acad. Sci.*, **19**, 389, 1933), in which he emphasizes the apparent irregularities in distribution and the much greater richness in the northern hemisphere.

The Harvard general survey now extends over more than one-third of the sky, and it is essentially complete to photographic magnitude 17·5. It is intended ultimately to include the whole sky, based on long-exposure photographs with the Bruce and Metcalf doublets at the South African and Oak Ridge stations of the Harvard Observatory.

Besides the general survey, the plan includes a detailed study of the individual nebulæ in conspicuous clusters and in a few typical areas, so as

to get, for faint nebulæ in general, some idea of the frequency distributions in angular diameter, magnitude, form, and structural detail. Two of these have already appeared, the first by Miss Ames, who catalogued 2778 objects in the constellations of Coma and Virgo, and the second by Prof. R. H. Baker of Illinois University, dealing with 985 objects in Eridanus in the south galactic hemisphere. The third paper, "A Further Study of 7900 External Galaxies," by Shapley, appears in *Proc. Nat. Acad. Sci.*, **21**, 587, 1935, which deals with 174 square degrees in the south galactic hemisphere in the constellations Dorado, Horologium, and Reticulum. This area lies between $\lambda = 215°$ to 245°, and $\beta = -38°$ to $-59°$. It is considered to be sufficiently remote from the galactic equator to be free from obscuration by outlying streamers from the "zone of avoidance." An examination of the distribution of apparent magnitudes reveals for this large region a greater deviation than usual from average space density, so that even outside the areas of conspicuous clustering, the number of nebulæ per square degree in the Horologium region is approximately twice the average found in the Harvard and Mount Wilson surveys. There is also a sudden increase in the number of nebulæ of magnitudes between 15·5 and 17·0, and this must be interpreted as evidence of the existence of a large "cloud" of nebulæ, with a maximum in the luminosity curve between magnitudes 17·0 and 17·5. If the nebulæ are normal systems the deduced distance of the "cloud" is of the average order of 22,000 kiloparsecs. The actual distribution in the "cloud" is very patchy, with at least half a dozen different centres of condensation, and 90 per cent. of the angular diameters range from 0′·2 to 0′·5; the dispersion in integrated apparent magnitudes being between 16·1 and 18·1. It is, of course, improbable that all of these objects should lie at approximately the same distance. There is no reason to think that the spatial depth of the cloud is likely to be much different from that which its angular diameter would indicate its width to be. As this is roughly a third of a radian, the nebulæ must extend over 7000 kiloparsecs in width and possibly much the same in depth. This consideration would account for some of the dispersion in angular diameters, and integrated magnitudes.

In H.C.O. 899 appears an interesting reference to the nebula I.C. 342 which has also been observed at Mt. Wilson (*Com.*, 116, 1934). It seems to have been first noticed by W. F. Denning in his sweeps for comets, but is now found to be only the nucleus of a very large condensed spiral 40′ × 33′. It lies in Camelopardus, R.A. $3^h{\cdot}40^m$ Dec. +67° 24′, $\lambda = 105°$, $\beta = +11°$, unusually close to the galactic equator. Owing to the numerical density of the galactic field stars, it is difficult to trace its extent, and possibly there is a certain amount of obscuration; but with an angular diameter of this size, the spiral must be one of the nearest to our Galaxy and comparable in distance with M 33, also a condensed spiral.

"A Study of Double and Multiple Galaxies" is the subject of an investigation by Erik Holmberg in *Lund Annals*, No. 6, 1937. The subject was suggested to him by Lundmark, the Director of the Lund Observatory, and the work was started there. But the great proportion of the matter contained in the memoir was obtained from the extensive collection of plates

taken with the Bruce refractor at Heidelberg by the late Max Wolf, Karl Reinmuth, and other members of the staff.

Holmberg's definition of a "double" galaxy is a system in which the angular distance between its components is equal to or smaller than the sum of the largest apparent diameters A^1 and A^2, so that $\frac{\theta}{A^1+A^2} \leq 2$: the same conditions are held to apply to a multiple system.

It may be, of course, argued that this criterion does not necessarily imply connection as physical systems, and in some cases the systems are apparently bi-nuclear, such as the well-known object in Canes, N.G.C. 5194/5. But the investigation is based on Lundmark's theory of "capture." According to Lundmark (*Upsala Medd.*, 30, 1927, and *Lund Circ.*, 9, 1934) the frequency of captures between the components of the "metagalactic" system is found to be very great, one in every 3500 years. These double physical systems will then act as condensation nuclei attracting new members. In this manner the systems will grow larger and larger, and the possibilities of the formation of groups and clusters are given.

Lundmark found about 200 double and multiple systems out of 8000 N.G.C. objects examined, and he concluded also that many of the small nebulæ appearing in the fields of large spirals are not satellites, but ordinary galaxies, their position near the large systems being the result of the tendency to clustering so apparent in the "metagalactic" system.

A list of these double and multiple systems is given by Holmberg. They amount to 827 and the total number of galaxies is 1854. In addition to the usual galactic co-ordinates, metagalactic co-ordinates are given, based on a pole at R.A. 323°, Dec. $= +66°{\cdot}5$, adopted by Lundmark; so far these metagalactic co-ordinates have not been adopted elsewhere than in the Swedish investigations. Some reproductions of the Heidelberg plates showing double and multiple nebulæ also appear.

The Dispersion in Absolute Magnitudes and Linear Dimensions of the Extra-galactic Nebulæ

This question is of fundamental importance in dealing with statistical studies of spatial distribution. Lundmark in 1927 (*Upsala Medd.*, 22, 1927) derived the absolute magnitudes and dimensions of 29 systems, taking the brightest resolved stars as a criterion of distance, and assuming an average absolute magnitude of $-7{\cdot}11$ for these stars. From these data he arrived at the following results :—

$$\overline{M} = -15^{m}{\cdot}8 \quad \overline{\log A} = +3{\cdot}35,$$
$$\sigma M = 1^{m}{\cdot}23 \quad \sigma \log A = 0{\cdot}43,$$

where M and A indicate the absolute photographic magnitude and the absolute major diameter in parsecs respectively.

Hubble took the brightest resolved stars as of an average absolute magnitude of $-6^{m}{\cdot}12$, and therefore got a smaller result, viz.

$$M = -14^{m}{\cdot}07, \qquad \sigma M = 0^{m}{\cdot}94.$$

In this investigation, however, elliptical nebulæ were excluded as well as spirals of an early type (Sa and Sb), so to this extent the material was not fully representative.

The real dimensions of the Galaxy are difficult to determine with any degree of certainty owing to the eccentricity in position of the solar system (about 4/5 from the galactic nucleus), and the presence of general absorption in galactic space, although 30,000 parsecs is usually accepted as a minimum. However, in a recent communication Gyllenberg suggests a value of $-18{\cdot}8$ M for the absolute magnitude of the Galaxy (*Lund Medd.*, II, 87, 1937), which is much larger than the average found above. There is still some doubt as to the value of the average dispersion in M, although it cannot be far from one magnitude. Thus for the Coma cluster $\sigma M = 1{\cdot}15 \pm 0{\cdot}05$ in *Mt. Wilson Cont.*, 427, but for the same cluster $\sigma M = 0{\cdot}94 \pm 0{\cdot}03$ in H.C.O. 896.

Bearing on this subject is a recent careful determination by R. O. Redman and E. G. Shirley of the integrated apparent magnitude of the Andromeda Nebula (M. 31) and the light distribution in and around the nucleus (*M.N.*, **97**, 416, 1937).

The first photographic attempt at the latter was made as long ago as 1913 by J. H. Reynolds (*M.N.*, **74**, 132, 1913), with a visual microphotometer. The light curve of the nucleus was then found to be very steep and to culminate in a quasi-stellar point. The present investigation has the advantage of much greater accuracy owing to the registering microphotometer, and the work has been carried out at the Cambridge Solar Physics Observatory. For the central regions photographs were taken with the 36-inch Common reflector; for the extended regions small-scale photographs with a 4-inch Aldis lens of 12-inch focal length were exposed. The large-scale plates were used to about 20′ from the centre along the major axis and 10′ along the minor. Measurements were made altogether to a diameter of 267′ along the major axis, and to a radius $44\frac{1}{2}'$ in one direction and 17′ in the other, where the subsidiary nebula N.G.C. 205 breaks the continuity.

With the assumption of minor axis symmetry beyond 17′ radius, the axis ratio of the isophotal contours varies from about 0·9 near the centre to 0·3 at the edge. This definitely confirms the globular form of the central part of the nucleus.

Shapley's measures of the major and minor axes on small-scale plates gave a major axis of 270′ and a minor axis of 240′. The authors think it open to question whether Shapley's figure for the minor axis should be accepted, on the ground that it is very difficult with small-scale photographs, taken with fast lenses and heavily over-exposed, to separate on microphotometer tracings the very faint nebulous extensions from small groups of stars. It is well known that the Andromeda Nebula lies in an extension of the galactic field unusually rich in small stars, and these must introduce complications, whether on microphotometer tracings from small-scale photographs or if photo-electric cells are used to measure radiation.

The central condensation of the nucleus is almost stellar in appearance and of 14·8 mag. per square second of arc when measures of light distribution

by E. G. Williams of some Mt. Wilson plates are taken into consideration. An unpublished spectrogram of the nuclear point at Mt. Wilson indicates a spectrum of a peculiar dwarf A type. If this spectrum is produced by dwarf A-type stars, with an average absolute magnitude of +1, the stellar density at the centre must be at least 1000 per cubic parsec; but the steep fall away from the centre would indicate only a tenth of this at a distance of 7 parsecs from the centre.*

The integrated magnitude of M31 without the two satellite N.G.C. objects is found to be $3^{m}.6$ against 5^{m} in the Shapley and Ames catalogue. As it is known that M31 and M33 are of about the same distance, owing to Hubble's work on the Cepheids observed in both, a comparison between the integrated magnitudes, and therefore the absolute magnitudes, may be made. The Shapley and Ames catalogue gives 7·0 mag. for the integrated magnitude of M33; it appears, therefore, that the difference in absolute magnitude between these two systems is at least 3 *M*. The two spirals are, however, of different types, M31 being *Sb* and M33 *Sc*, and the latter is a much rarer type than the former.

The nucleus of M33 is quite different in character from that of M31; in this case there is no steep light curve up to a central point, but the spiral arms spring from a hazy mass which is almost of constant surface brightness and has a diameter about 1′·5. Some stellar or quasi-stellar objects are found involved in this area, as well as along the spiral arms. Excluding these objects, the maximum surface brightness of the "hazy mass" is about $20^{m}.3$ per square second of arc.

Photo-electric Magnitudes and Colours of Extra-galactic Nebulæ

Until recent years estimates of the total integrated luminosities of extra-galactic nebulæ have been made only by photographic means in which the density and extent of the nebular images have been compared with stars of accurately known magnitudes. But such a method has serious disadvantages in that a comparison is attempted between diffuse luminous areas and stellar point sources, and in making this transformation large systematic errors may be introduced. In 1930 J. Stebbins was the first to employ a photo-electric cell for the purpose of measuring integrated luminosities of these nebulæ; it is well adapted for such measurements, as it integrates all the light that comes into it through the diaphragm and gives an electric current proportional to the total brightness. Its advantage over the photographic method should be specially noticeable in the case of nebulæ of large angular diameter, which include all the systems nearest to us, the distances of which are known approximately from the Cepheid variables and other stars contained in them. These near systems are in fact the base of the magnitude scale of nebulæ.

* The smooth character of the nebulosity light curve, however, gives no indication whatever of stellar resolvability, such as is so evident in the outer regions, and it is an extrapolation to regard the peak of the curve as "stellar" in any other sense than that an absorption spectrum is shown.

In *Mt. Wilson Cont.*, 543, 177, 1936, A. E. Whitford gives an account of his observations of the integrated luminosities of eleven nebulæ of large angular diameter.

A short-focus telescope was required in order to include the necessary area in the field of view of the photo cell, so the photometer was attached to the 10-inch Cooke photographic telescope. The galvanometer deflections were recorded photographically on a drum ; the largest focal-plane diaphragm that could be used was 10 mm. in diameter, corresponding to a field of 30′ of arc. But in order to get reliable results it was necessary to eliminate two inevitable complications—the luminosity of the sky background and the luminosity of stars in the field, both of which were included in the galvanometer readings.

Numerical corrections for these factors were difficult to make and some discordances in the results could not be avoided. Especially difficult to deal with were the objects of very large angular diameter such as the Andromeda Nebula, where a $3\frac{1}{2}$-inch Tessar lens was used instead of the 10-inch refractor.

The table of the ultimately adopted photographic magnitudes is compared with the Harvard magnitudes; the discrepancies between the two range from 0 to 1·1 mag., but as Redman and Shirley point out in their paper (*loc. cit.*) the diaphragm should be large enough to include the luminosity from the outer regions of the nebulæ, which apparently has not always been the case.

In *Mt. Wilson Cont.*, 577, 1937, details are given by Stebbins and Whitford of a much more extensive application of the photo-electric cell to the determination of nebulæ magnitudes, in this case down to 15 m. The total number measured was 165, and of these 112 were measured also for colour excess or deficiency. The instruments used were, first the 60-inch reflector and later the 100-inch reflector; for faint nebulæ the electrometer was found to be unsuitable, so an amplifier was substituted in the installation.

In addition to the nebulæ, colour measurements of most of the globular clusters accessible at Mt. Wilson were made with the photo cell and a pair of colour filters. Details of the work on globular clusters is given in *Mt. Wilson Cont.*, 547, 1936. As the spectrum of the nebular nuclei in many cases is comparable with that of dwarf stars, 60 dwarf stars were also observed in the apparatus, the great majority of which gave a small positive colour correction. The integrated magnitudes of the smaller nebulæ compare well with the Harvard photographic catalogues, the difference $Pgp - HPg$ being small.

The nebulæ of types E, *Sa* and *Sb* are nearly uniform in colour; those of type *Sc* are more varied, as might be expected, from the greater stellar resolvability in this type. The colours of the first three types indicate a colour excess of +0·99, which is evidently intrinsic as there is no evidence of selective absorption in inter-nebular space.

J. H. REYNOLDS.

MINOR PLANETS

Two hundred and eighteen planets were discovered or first announced in 1937. The first letter of the planet's designation gives the approximate date of discovery; for the first half of January the first letter is A, for the second half B, and so on; I and J being treated as a single letter, December discoveries begin with X or Y.

H. Alikoski (Turku) QD; A. Bohrmann (Heidelberg) RL, VF, VG, VH; L. Boyer (Algiers) BA, CD, CE, EA, EC; E. Delporte (Uccle) CG, ED, GC, GD, JF, LC, LG, LH, NA, RJ, TA, UC, WB; K. Inkeri (Turku) GB; C. Jackson (Johannesburg) EG, GF, JG, JH, JJ, JK, JN, JO, KA, KB, KC, KD, KE, KF, KG, LJ, LK, LL, LM, LN, LO, LP, LQ, ND, NF, NG, NH, NJ, NK, NL, NM, NN, NO, NP, NQ, NR, NS, NT, NU, NV, NX, OA, OB, OC, PF, PG, PH, PJ, PK, QF, QG, QH, RB, RK, RM, RN, RO, RP, SA, VE, 1936 YK; G. Kulin (Buda-Pest) AD, BB, JA, WA, YC, YD, YF; M. Laugier (Nice) AF, AG, AH, AQ, BC, CH, EF, GF, JL, JM, LA, LB, NB, NC; G. Neujmin (Simeis) GK, GL, GM, NE, QA, QB, RA, RE, RF, RG, RH, TJ, TK, TL, TM, TN, TO, XA; A. Patry (Nice) AB, AC, AE, AG, CF, GE, QA, QB, RD, VA, YA, YB; M. Protic (Belgrade) JB, WD, WE; K. Reinmuth (Heidelberg) AK, AL, AM, AN, AP, CA, CB, GG, GH, GJ, JC, JD, JE, LD, LE, LF, PA, PB, PC, PD, PE, TB, TC, TD, TE, TF, TG, TH, UB, UD, UE, UF, UG, VJ, YF, YG. The image of CA was a long streak, the direction of motion being doubtful. G. Reiss (Algiers) CC; F. Rigaux (Uccle) EB, RC; H. U. Sandig (Bergedorf) QC; R. Schorr with W. Dieckvoss (Bergedorf) AA; Y. Väisälä (Turku) AJ, FA, GA, WC, YB, YE; G. van Biesbroeck (Yerkes) 1936 FR, FS, YJ, 1937 AR, AS, CJ; A. A. Wachmann (Bergedorf) TB, TC, TD, TE, TF, TG, TH.

Also the following planets found on plates taken in 1929 by H. van Gent (Johannesburg) 1929 NE, SI, UE; 1930 KH, KJ, LA, MO, OG, OH, OJ, OK, OL, OM, ON, QU, SY, SZ, SA_1, SB_1.

The following planets have received permanent numbers :—

1381 = 1930 QJ	1391 = 1936 DA	1401 = 1935 UD	1411 = 1937 AM
1382 = 1925 BB	1392 = 1936 FO	1402 = 1936 OC	1412 = 1937 BA
1383 = 1934 RV	1393 = 1936 KD	1403 = 1936 QA	1413 = 1937 CD
1384 = 1934 RX	1394 = 1936 MD	1404 = 1936 QW	1414 = 1937 CE
1385 = 1935 MJ	1395 = 1936 OB	1405 = 1936 RE	1415 = 1937 EA
1386 = 1935 PA	1396 = 1936 PF	1406 = 1936 RF	1416 = 1937 EC
1387 = 1935 QD	1397 = 1936 PG	1407 = 1936 WC	1417 = 1937 GH
1388 = 1935 SS	1398 = 1936 QL	1408 = 1936 WF	
1389 = 1935 SS_1	1399 = 1936 QY	1409 = 1937 AK	
1390 = 1935 TA	1400 = 1936 WA	1410 = 1937 AL	

The following have received names :—

793 Arizona ; 1229 Tilia ; 1230 Riceia ; 1234 Elyma ; 1249 Rutherfordia ; 1250 Galanthus ; 1251 Hedera ; 1269 Rollandia ; 1282 Utopia ; 1321 Majuba ; 1323 Tugela ; 1356 Nyanza ; 1368 Numidia ; 1370 Hella ; 1371 Resi ; 1372 Haremari ; 1373 Roberbauxa ; 1380 Volodia ; 1381 Danubia ; 1382 Gerti ; 1383 Limburgia ; 1384 Kniertje ; 1385 Gelria ; 1386 Storeria ; 1388 Aphrodite ; 1389 Onnie ; 1395 Aribeda ; 1404 Ajax ; 1937 UB Hermes ; 1931 RJ = 1931 TF = 1935 OM Radcliffe.

The planets 1937 PB and 1937 QD are Trojans, on the side of Jupiter of greater longitude. The planet 1937 UB Hermes made the closest approach to the Earth of any known body other than the Moon ; it left a trail 42′ in length on a plate taken by K. Reinmuth at Heidelberg on October 28 (exposure 2 hours). Images were then found on plates taken at Sonneberg October 26·93, October 28·01, October 28·98, October 29·93 ; also at Oak Ridge (Harvard) October 25, and at the Union Observatory, Johannesburg ; the latter images, in combination with those secured in Europe, were of assistance in determining the distance from the Earth. The following orbits by Mr. L. E. Cunningham (*Harvard Card*, 440) include approximate perturbations by the Earth.

Date of Osculation	1937 Oct. 28·0 U.T.	1937 Nov. 5·0
T	1937 Dec. 18·8969 U.T.	1937 Dec. 18·8014
ω	90° 41′ 15″·9	90° 26′ 3″·1
Ω	35° 9′ 18″·0	35° 8′ 5″·3
i	6° 13′ 34″·9	6° 9′ 18″·5
q	0·6165607	0·6179177
e	0·6246857	0·6257652
P	2·1056 y	2·1217 y
Equinox	1937·0	1937·0

g is given as 17·4 mag., implying a diameter somewhat less than a mile.

The nearest approach to the Earth was at October 30·5, distance 485,000 miles, less than half the distance of Adonis in 1936. The least distance between the orbits of Hermes and the Earth was 220,000 miles.

A. C. D. CROMMELIN.

COMETS

The year began with the unexpected recovery of a long missing comet, that of Daniel, 1909 IV, 1937 *a* ; most computers had given it up as lost, but Mr. H. Hirose, in Japan, made a very accurate determination of its orbit and perturbations, which led to its recovery by Mr. Simizu in Japan on January 31, very near the predicted place ; in addition to the Japanese observations, it was seen at Oak Ridge, Harvard, by Mr. L. E. Cunningham on February 12 ; it was ill-defined, 15″ in diameter, magnitude 15 ; L. Volta observed it at Pino Torinese on April 1. H. Hirose is continuing the study of its perturbations.

Comet 1937 *b* was discovered by Dr. F. L. Whipple at Harvard on February 12 ; it was then of magnitude 12, diffuse, with central condensation

and a short tail; on April 29 its magnitude was 8·6; on May 12 it was 8·2; there was a faint short broad tail in P.A. 130°; it was followed till November.

Comet 1937 *c* was discovered by Professor Wilk at Krakow on February 27; it was of magnitude 7, and was diffuse, without central condensation or nucleus. It was independently found by Mr. L. Peltier of Delphos, Ohio; this is the second time that these two observers have independently discovered a comet; their first joint discovery was 1925 XI. 1937 *c* had already passed perihelion at discovery; it was observed till May 8.

An announcement of a cometary discovery by Mr. Kozawa on March 9 was withdrawn as erroneous. Another discovery, 1937 *d*, was reported by Mr. W. Gale of Waverley, near Sydney, on April 6; the object was described as of magnitude 10, and was 8′ south of Mars; he gave four positions referred to Mars, but the comet was not seen elsewhere, in spite of careful search at Yerkes Observatory.

Mr. Gale's positions are:

	d	h	m				s	′	
1937 Apr.	7	15	25	U.T.	Object precedes Mars by		6	S.	10¼
	11	14	10		,,	follows ,,	29½	S.	9
	16	18	0		,,	,, ,,	47	S.	3¼
May	5				,,	,, ,,	7	S.	8

Table of Elements of Cometary

Comet	Name	*T* in U.T.	ω	Ω	*i*
			° ′ ″	° ′ ″	° ′ ″
1912 II	Gale	1912 Oct. 4·95828	25 37 56	297 0 11	79 48 20
1921 I	Dubiago	1921 May 4·85344	97 25 31	66 4 42	22 20 5
1922 II	Baade	1922 Oct. 26·03015	118 18 26	220 28 57	51 27 50
1923 III	Bernard-Dubiago	1923 Nov. 17·84807	255 19 59	226 39 57	113 47 54
1924 I	Reid	1924 Mar. 13·49153	271 27 18	114 1 6	72 19 35
1927 IV	Stearns	1927 Mar. 22·72349	11 8 14	214 37 51	87 39 37
1929 I	Schw.-Wach. (2)	1929 May 12·85339	357 42 11	126 0 53	3 43 51
1931 III	Nagata	1931 June 11·76670	320 9 0	191 16 26	42 18 15
1932 X	Dodwell-Forbes	1932 Dec. 30·53031	327 20 27	77 40 15	24 30 5
1933 IV	Whipple	1933 Aug. 1·096	190 26 17	188 33 56	10 12 53
1935 I	Johnson	1935 Feb. 26·46876	18 23 16	91 32 35	65 25 34
1936 IV	Hubble	1936 Nov. 16·38230	146 33 11	97 20 55	11 39 26
1936 IV	Hubble	1936 Nov. 21·76373	148 31 0	96 41 25	11 30 8
1937 *a*	Daniel	1937 Jan. 27·876	6 0 40	70 18 50	19 49 30
1937 *c*	Wilk-Peltier	1937 Feb. 21·84934	32 10 52	56 51 50	26 20 0
1937 *e*	Grigg-Skjellerup	1937 May 22·51 Pre. / 23·05 obs.	355 16 27	215 33 34	17 26 48
1937 *b*	Whipple	1937 June 20·07782	107 45 5	127 43 37	41 32 59
1937 *f*	Finsler	1937 Aug. 15·6821	114 51 4	58 32 3	146 25 17
1937 *h*	Encke	1937 Dec. 27·25 Pre. / 27·73 obs.	184 56 52	334 41 28	12 32 50

Mr. Gale sent the following notes, which are published in *Annuaire Astronomique* for 1938: "On April 7 it had moved about 2′ East relatively to Mars; it had a strong condensation at the preceding end and a broad, feeble bifurcated tail 40″ long. Several observers saw it, with some variations of light." Mr. Gale saw it for the last time on May 5, on which day it had a faint tail 30″ long.

1937 *e* was the periodic comet Grigg-Skjellerup; it was found by Mr. L. E. Cunningham at Harvard on April 30, being of magnitude 13: the position indicated a correction of $+0^{d}\cdot54$ to the prediction of T in the *Handbook* of the B.A.A. for 1937, the corrected value being 1937 May 23·05. The comet had a faint coma 40″ in diameter, with a condensation 10″ in diameter. Total magnitude 13·4 (*Harvard Card*, 414); subsequently an image was found on a plate taken at Yerkes on March 29; magnitude 15·5. It was observed at Pino Torinese on May 6, magnitude 13, and at Simada, Japan, on May 2 and 4 (*U.A.I. Circs.*, 657, 659), and at Athens on June 2 and 9. Professor G. van Biesbroeck followed it till July.

Comet 1937 *f* was discovered on July 4 by Dr. Finsler at Zürich; it was then of magnitude 7, but became a conspicuous naked-eye object with a long multiple tail; it was well placed for northern observers, reaching north declination 78° on August 3. It was in perihelion on August 15,

Orbits published in 1937

Comet	Log q	Period in Years or Eccentricity e in Hyperbolic Orbits	Equinox	Computer	Reference
1912 II	9·854982	56649	1912·0	G. Peisino, E. de Caro	*V.J.S.*, **72**
1921 I	0·047547	67·010	1921·0	H. Hirose	*V.J.S.*, **72**
1922 II	0·353872	1·000865 *e*	1922·0	A. Gennaro	*A.N.*, **259**, 311
1923 III	9·890886	...	1923·0	S. Kanda	*Tokyo Astr. Obs.*, **4**, 2
1924 I	0·244545	26374	1924·0	M. Campa	*V.J.S.*, **72**
1927 IV	0·566288	83064	1927·0	Z. Shen, I. Imai	*V.J.S.*, **72**
1929 I	0·320244	6·42311	1925·0	G. Reiss	*U.A.I. Circ.*, 683
1931 III	0·019905	356·37	1931·0	Z. Shen, I. Imai	*V.J.S.*, **72**
1932 X	0·053382	262·06	1933·0	A. D. Maxwell	*A.J.*, **45**, 65
1933 IV	0·397143	7·4861	1933·0	A. D. Maxwell	*Michigan Pub.*, **6**, 6
1935 I	9·996206	1216·4	1935·0	A. D. Maxwell	*A.J.*, **45**, 49
1936 IV	0·285197	...	1937·0	A. D. Maxwell	*U.A.I. Circ.*, 691
1936 IV	0·288630	2509	1937·0	H. Duborg	*U.A.I. Circ.*, 702
1937 *a*	0·18664	6·8246	1937·0	H. Hirose	*U.A.I. Circ.*, 646
1937 *c*	9·793426	...	1937·0	J. Febrer, S. Ribot	*U.A.I. Circ.*, 660
1937 *e*	9·95798	5·0220	1937·0	P. J. Harris, W. P. Henderson	*B.A.A. Handbook*, 1937
1937 *b*	0·238870	3430000	1937·0	M. Davidson	*U.A.I. Circ.*, 662
1937 *f*	9·9358527	8618	1937·0	G. F. Kellaway	*U.A.I. Circ.*, 678
1937 *h*	9·521592	3·2836	1937·0	A. C. D. Crommelin	*B.A.A. Handbook*, 1937

q being 0·86 ; it was followed till the end of August. Two photographs taken by M. Quénisset at Juvisy on August 3 and 6 are reproduced in the *B.A.A. Journal* for October. The tail was traced for 20° on the negatives. On August 3, J. Ellsworth at Lyons observed the recession of a portion of its tail through 18′ in $1\frac{1}{4}$ hours, the speed being about 100 km./sec. (*A.N.*, 6316).

Comet 1937 *g* was discovered by Dr. Hubble at Mt. Wilson on August 4 ; its magnitude being 13 ; it was diffuse, without central condensation or nucleus ; it was found to have passed perihelion on 1936 November 16, and is therefore 1936 IV, but it was then badly placed for observation, being nearly behind the Sun. It remained faint, but there were many observations, including a good series at the Union Observatory, Johannesburg. The orbit is elliptical, but with a very long period.

Comet 1937 *h* is Encke's Periodic Comet, this being its fortieth observed apparition. Dr. H. M. Jeffers found it photographically at the Lick Observatory on September 3, its magnitude being 18. The indicated date of perihelion was about 1937 December 27·74, which is $0^d{\cdot}49$ later than the prediction in *B.A.A. Handbook*, and about $0^d{\cdot}11$ later than Professor L. Matkiewicz's prediction as deduced from his ephemeris in *U.A.I. Circ.*, 681. The photographs in September and October showed a sharp nucleus with a faint coma, which developed on October 9 to a fan-shaped tail 0′·8 long (*Harvard Card*, 433). The American observers, using the formula $1/r^6\Delta^2$ for the brightness, predicted that the comet would rise to magnitude 5 at perihelion ; it did, in fact, reach magnitude 5 early in December, being observed by M. Quénisset at Juvisy almost down to the horizon. A discussion of Geddes' Comet, 1932 VI, by Professor van Biesbroeck gave the law $1/r^{4\cdot4}$, so it seems to vary with different comets.

Two other comets, found in former years, were under observation in 1937 ; van Biesbroeck's Comet, 1935 *d*, was observed by its discoverer and at Lick and Bergedorf till the autumn ; it was in N. decl. 86°, magnitude 16 ; and the comet Schwassmann-Wachmann (1) 1925 II, and 1927 *j*, which was discovered in 1927, and has been seen every year since then, except 1936, was again observed, and continued to exhibit the remarkable variations of brightness that it showed in other years. It is due at perihelion about September 1941.

A. C. D. CROMMELIN.

SOLAR ACTIVITY

Sunspots.—The year 1937 was one of great sunspot activity, probably unequalled since 1870–71. A fairly definite peak in frequency occurred last July, but it would be premature to ascribe this to the maximum peak of the present cycle, though it is not improbable. Amongst other manifestations of solar activity that have increased concurrently with sunspots are bright chromospheric eruptions which, since the last solar minimum, have been observed in a systematic manner and have already provided unique data for comparison with disturbed conditions in the ionosphere.

Groups of sunspots or single spots large enough to be seen with the naked eye have been frequent during 1937. Spots thus visible near the centre of the disc are usually found to have an area of about 500 millionths of the Sun's hemisphere or greater. Seventeen groups seen during the year reached double this area; their time (U.T.) of central meridian passage and latitude are tabulated below.

(1)	Jan.	24·2	19° S		
(2)	Jan.	31·2	11° S		
(3)	Apr.	22·4	9° S		
(4)	Apr.	23·2	25° N		
(5)	Apr.	24·6	19° N		
(6)	Apr.	29·6	21° S		
(7)	May	20·6	15° S		
(8)	June	4·9	13° N		
(9)	June	16·9	15° S		
(10)	July	9·1	23° N		
(11)	July	28·5	31° N		
(12)	Aug.	5·8	23° N		
(13)	Aug.	14·3	11° N		
(14)	Aug.	25·3	33° N		
(15)	Sept.	10·9	11° N		
(16)	Oct.	4·5	9° N		
(17)	Dec.	20·9	26° N		

Groups Nos. 11 and 16 both reached a maximum area of 3000 millionths of the Sun's hemisphere and are the largest groups observed since 1926 January. Nos. 2 and 5 exceeded 2000 millionths in area. The initial rapid development of Nos. 5 and 11 took place on the visible hemisphere. Nos. 5, 6, 7, 9 and 16 were very active spectroscopically.

The year 1937 was also one of considerable terrestrial magnetic activity. Twenty-six magnetic storms were recorded at Abinger, the lower limit of ranges for inclusion as a storm being for $D \geqslant 30'$ or for H or $V \geqslant 150\ \gamma$. The corresponding number of storms in 1936 was nine, and eight in 1935. Three of the storms in 1937 had ranges in H exceeding 300 γ and are therefore classified as "great" storms. These three storms, commencing respectively on April $25^d\ 15^h{\cdot}7$, April $26^d\ 17^h{\cdot}7$ and April $27^d\ 18^h{\cdot}7$, and preceded by a smaller storm on April $24^d\ 12^h{\cdot}0$, form a notable group of disturbances which all commenced within a few days of the time of central meridian passage on April $24^d{\cdot}6$ of the large and active group of sunspots, No. 5. According to the Zürich *Bulletin*, No. 38, 32 bright chromospheric eruptions were collectively observed in association with this group as it crossed the disc. On the other hand, two other almost equally active spots, Nos. 7 and 9 (as assessed by the observed number of bright eruptions), were not associated near the time of their respective central meridian passages with magnetic storms. There was, however, a small but distinctive disturbance in H in the case of No. 7, commencing on May $21^d\ 16^h{\cdot}0$.

H. W. NEWTON.

Prominences.—The mean daily areas and numbers of calcium prominences as derived from Kodaikanal photographs are as follows :—

Areas

	North	South	Total
1937 January to June	3·61	4·19	7·80 sq. mins.
July to December	3·65	3·03	6·68 ,,

Numbers

	North	South	Total
1937 January to June	7·11	8·08	15·19
July to December	8·79	7·67	16·46

Calcium areas show a slight increase of less than one per cent. over the previous year, but there has been an increase of 7 per cent. in numbers. The activity is almost equally divided between the northern and southern hemispheres. The distribution in latitude of areas and numbers has continued to be irregular. The peak in the northern hemisphere has advanced 10° towards the poles from its position in 1936, but that in the southern hemisphere has advanced 15° towards the poles. Both the peaks have become less marked.

Sixty metallic prominences were observed during 1937 as against 64 in the previous year. Of these 39 were in the northern hemisphere and 21 in the southern hemisphere, and all these were between latitudes 1° and 40°. Displacements of the hydrogen line in the chromosphere and prominences observed during the year with the spectroscope numbered 369 as against 407 in 1936. Of these 200 were towards the red, 144 towards the violet, and 25 both ways simultaneously.

Bright reversals of the *Hα* line over the Sun's disc observed with the spectroscope in the neighbourhood of sunspots numbered 891 as against 745 in the previous year. The displacements observed numbered 73 as against 99 in the previous year. Of these 40 were towards the red, 17 towards the violet, and 16 both ways simultaneously. D_3 was observed as a dark line on 826 occasions against 734 in 1936.

With the spectrohelioscope, 259 displacements were observed in prominences as against 197 in the previous year. Of these, 151 were in the northern hemisphere and 108 in the southern, and 145 were on the east limb and 114 on the west limb. Displacements to the red numbered 131, and those to the violet numbered 128. The largest displacement in prominences observed in 1937 was 3·4 A. to the violet.

On 16th June 1937 a bright eruption was noticed in the north-west quadrant of the Sun near the central meridian where a sunspot group was situated. While the bright eruption itself was not noteworthy, a dark marking in its neighbourhood exhibited great activity. It changed its shape and extent rapidly from $9^h\ 50^m$ to $10^h\ 14^m$ A.M. I.S.T. and became insignificant by $11^h\ 0^m$. Displacements to the extent of 1·6 A. to red and 2·6 A. to the violet were noticed on it during its active phases.

The mean daily areas of prominences projected on the disc as hydrogen absorption markings amounted to 9490 millionths of the Sun's visible hemisphere as against 8973 millionths in the previous year, showing an increase of 6 per cent. Their distribution in latitude is similar to that of calcium prominences, except that the activity in the lower latitudes has become much more pronounced than in the previous year, and that, towards the end of the year, the activity near the poles has practically ceased.

A. L. NARAYAN.

DOUBLE STARS

New Pairs.—Kuiper (*Ap. J.*, **84**, 478; **85**, 255) gives two new binaries of large parallax. Luyten (*Harv. Bull.* 906) and van de Kamp (*P.A.S.P.*, **48**, 313) give two faint pairs having a large proper motion. Wilson has observed 82 Gem and Polaris as double stars with the interferometer on the 18-inch Flower refractor (*P.A.S.P.*, **49**, 202). Peek (*J.B.A.A.*, **47**, 232) writes on occultations of τ Tauri, which tend to show that it is a double star. Milburn gives his new pairs 998–1025 together with some measures of known pairs, all with the 24-inch reflector (*M.N.*, **97**, 222). Barton has collected pairs from the Melbourne and Sydney astrographic catalogues (*A.N.*, **263**, 347 and 383).

Measures.—Van Biesbroeck has published his second series of measurements with the 40-inch refractor (*Yerkes Pub.*, 8, pt. 2). Simonow (*Berlin-Babelsberg Veröff.*, **11**, heft 5) gives his measures with the $25\frac{1}{2}$-inch refractor, with a thorough investigation of their systematic errors. Strand (*Leiden Ann.*, xviii, pt. 2) gives photographic measurements and orbits of six well-known binaries. Measures with the Johannesburg $26\frac{1}{2}$-inch refractor are given in *U.O.C.* 96 (20th series, by van den Bos; 21st series, by Finsen) and 98 (22nd series, by van den Bos). Baize's measures with the Paris 12-inch are contained in *J.d.O.*, **19**, 211; **20**, 60, 97 and 111. Duruy (*J.d.O.*, **20**, 142) gives measures with a $7\frac{1}{2}$-inch, Filippoff (*J.d.O.*, **20**, 74) with a $12\frac{1}{2}$-inch, Krüger (*Contr. Brera Milano*, 33) with a 19-inch and Pokrowsky (*Poulkovo Obs. Circ.* 20) with a 15-inch refractor. Danjon (*Strasbourg Ann.*, iii, pt. 4, 227) gives measures with an interferential micrometer on the 19-inch. Luplau Janssen (*A.N.*, **262**, 317) has continued his measures with the 10-inch, Schembor (*A.N.*, **262**, 459) with the 8-inch.

Orbits:—

ADS	Computer	*P*	*a*	*e*	Reference
			"		
61	Volet	107·25	1·444	0·445	*J.d.O.*, **20**, 59.
520	van den Bos	25·00	0·670	0·22	*U.O.C.* 98.
671	Strand	526·0	12·534	0·53	*Leiden A.*, xviii, 2.
940	Varchon	(3554)	(1·82)	(0·81)	*J.d.O.*, **20**, 54.
1630	Woolley, Symms	56·0	0·32	0·92	*M.N.*, **97**, 444.
1865	Finsen	25·2	0·546	0·26	*U.O.C.* 98.
2200	Moore	30·7	0·22	0·76	*A.J.*, **46**, 162.
3135	Symms	89·20	0·53	0·614	*M.N.*, **97**, 635.
	Kuiper	92·2	0·526	0·605	*Ap. J.*, **86**, 166.
	van den Bos	90·0	0·570	0·61	*U.O.C.* 98.
3210	Kuiper	30·4	0·236	0·20	*Ap. J.*, **86**, 166.
3248	van den Bos	40	0·420	0·35	*U.O.C.* 98.
3264	Kuiper	170	1·029	0·82	*Ap.J.*, **86**, 166.
3475	,,	16·34	0·1895	0·445	,, ,,
3483	,,	116·2	0·790	0·62	,, ,,
4299	van den Bos	20·57	0·210	0·29	*U.O.C.* 98.
5752	Finsen	36·7	0·256	0·52	,, ,,
6420	Woolley, Symms	23·18	0·58	0·69	*M.N.*, **97**, 449.
6483	van den Bos	62·5	0·337	0·55	*U.O.C.* 98.
8048	Finsen	23·5	0·23	0·12	,, ,,

ADS	Computer	*P*	*a*	*e*	Reference
			"		
8630	Strand	171·37	3·746	0·8808	*Leiden A.*, xviii, 2.
8739	,,	89·6	1·269	0·38	*B.A.N.* 305.
9343	van den Bos	126	0·600	0·962	*U.O.C.* 98.
9352	,,	50·6	0·657	0·09	,, ,,
9378	Simonow	87·71	0·325	0·536	*Babelsberg V.*, **11**, 5.
9413	Strand	149·95	4·884	0·506	*Leiden A.*, xviii, 2.
9494	,,	219·5	3·609	0·42	,, ,,
9689	Finsen	54·6	0·250	0·61	*U.O.C.* 98.
9744	Wilson, orbit I	11·20	0·11	0·90	*A.J.*, **46**, 153.
	II	22·00	0·22	0·00	
	van den Bos I	10·65	0·117	0·80	*U.O.C.* 98.
	II	21·30	0·230	0·00	
9757	van Biesbroeck	90·0	0·68	0·48	*Yerkes P.*, **8**, 11.
9979	Strand	1162·0	7·274	0·80	*Leiden A.*, xviii, 2.
9982	Woolley, Symms	680	3·04	0·86	*M.N.*, **97**, 168.
10360	Wilson	16·08	0·167	0·144	*P.A.S.P.*, **48**, 309.
10561	Finsen	36·7	0·228	0·56	*U.O.C.* 98.
10871	,,	38·4	0·276	0·45	,, ,,
11046	Strand	87·85	4·558	0·4988	*Leiden A.*, xviii, 2.
11111	van den Bos	391	1·330	0·67	*U.O.C.* 98.
11950	Finsen	20·80	0·520	0·23	,, ,,
12447	,,	474	1·35	0·94	,, ,,
12889	Strand	184·5	3·75	0·95	*B.A.N.* 305.
12973	Finsen	22·8	0·146	0·85	*U.O.C.* 98.
13723	van Biesbroeck	95·0	0·33	0·77	*Yerkes P.*, **8**, 11.
14238	Finsen	107·7	0·492	0·90	*U.O.C.* 98.
14839	,,	63	0·52	0·74	,, ,,
15267	van Biesbroeck	119·0	0·35	0·31	*Yerkes P.*, **8**, 11.
16417	,,	27·0	0·41	0·65	,, ,,
B 1909	van den Bos	5·56	0·145	0·61	*U.O.C.* 98.
I 17	Finsen	128	1·47	0·29	,, ,,
λ 143	van den Bos	115	0·740	0·58	,, 96.
γ Cen	,,	84·50	0·930	0·790	,, ,,
λ 258	Finsen	26·7	0·377	0·39	,, 98.
R 321	,,	108	0·753	0·68	,, ,,

Alden (*A.J.*, **45**, 193) discusses the apparent orbit of δ Aql, Szkalnitzky (*A.N.*, **263**, 437) writes on 70 Oph. *The Observatory* (**60**, 302) advises orbit computers that the orbits of the pairs ADS 450, 7284, 8148, 8539, 8987 and 14073 have been computed and will be published in the near future.

Miscellaneous.—Aitken (*P.A.S.P.*, **48**, 340) has a note on Nova Herculis and Polaris, Kuiper on Nova Herculis (*Ap. J.*, **86**, 102) and on the magnitude of the companion to Procyon (*Ap. J.*, **85**, 253). Pitman gives the parallax and mass ratio of ϵ Hydræ (*A.J.*, **46**, 82), van de Kamp the mass ratio of β 648 (*A.J.*, **46**, 36; *P. Am. Astr. Soc.*, **9**, 8). Crawford has a note on the orbit of OΣ 536 (*P.A.S.P.*, **49**, 37), Luyten on the orbit of κ Peg (*Ap. J.*, **85**, 398), Woolley on the orbit of ADS 1640 and the relative radial velocity of ADS 6420 (*Obs.*, **60**, 114), and Strand on the dynamical parallax of ADS 12913 (*B.A.N.* 305).

Hynek gives a preliminary report on the axial rotation of visual binaries

(*P. Am. Astr. Soc.*, **9**, 7). Brown (*M.N.*, **97**, 56, 62 and 388) writes on the stellar problem of three bodies, with application to the perturbations in ξ UMa; van den Bos on differential correction of the orbit of a visual binary (*U.O.C.* 98). Bemporad (*Pino Torinese*, 27) discusses the evolution of double-star orbits, and von Schelling (*A.N.*, **261**, 265) the two-body problem for the case of Jeans's law of diminishing masses. Schlesinger has a note on the accuracy of double-star measurements (*P.A.S.P.*, **49**, 39), Barnes on the statistical determination of the masses and parallaxes of binary stars (*M.N.*, **97**, 454), and Ambarzumian on the statistics of double stars (*A. J. Sovj. U.*, **14**, 219).

Card Catalogues.—A request for information received here shows that the present position is not generally understood. The card catalogue of double stars north of $-30°$ is still in the hands of Dr. R. G. Aitken, whose present address is 1109 Spruce Street, Berkeley, California. The card catalogue of double stars south of $-19°$ is kept at the Union Observatory, Johannesburg, South Africa. Information on discoveries, measures, orbits, etc. can be obtained, for these two regions of the sky, from the appropriate central office. On the other hand, it will be appreciated by these two offices if reprints of papers dealing with double stars, especially those published in the less accessible periodicals, are sent to them by the authors.

W. H. VAN DEN BOS.

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE CONTRIBUTED TO THE LIBRARY, ETC., DURING THE YEAR 1937

(*Institutions exchanging publications with the R.A.S. Library are omitted from the list, in order to economise in printing*)

Aarhus, Ole Rømer Observatoriet
The Air Ministry
American Astronomical Society
Association of Special Libraries and Information Bureaux
Astronomical Society of South Africa
Baltic Geodetic Commission
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Belfast, Queen's University
Belgrade, Observatoire Astronomique de l'Université
Bern, Schweizerische Geodätische Kommission
Bordeaux, Société des Sciences Physiques et Naturelles
Breslau Observatory
Brussels, Institut d'Astronomie de l'Université
Canton, Observatoire de l'Université Sun Yatsen
Carnegie Institution of Washington
Cracow, Académie Polonaise des Sciences et des Lettres
Crohamhurst Observatory, Queensland
Genève, Société Astronomique Flammarion
Gorki (Nishni-Novgorod), Verein von Freunden der Physik und Astronomie
Helsingfors, Finnisches Geodätisches Institut
Hyderabad, Nizamiah Observatory
International Astronomical Union
Kyoto, Oriental Astronomical Association
London, The Physical Society
London, Royal College of Science Association
London, Science Museum
London University
Los Angeles, Society for Research on Meteorites
Louvain, Laboratoire d'Astronomie et de Géodésie de l'Université
Manchester, Literary and Philosophical Society
Mauritius, Royal Alfred Observatory
Merate, Reale Osservatorio Astronomico
Minneapolis, Astronomical Observatory of the University of Minnesota
Moscow, Astronomical-Geodetical Society of U.S.S.R.
Nantucket, Maria Mitchell Association
Netherlands Indies Science Council
Newtonian Society
New York, Rutherford Observatory of Columbia University
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ADDRESS

Delivered by the President, Dr. H. Spencer Jones, on the award of the Gold Medal to Dr. W. H. Wright.

The Gold Medal of the Society has been awarded to Dr. William Hammond Wright for his studies of the spectra of gaseous nebulæ and of novæ, and for his work on the photography of planets in light of different colours.

Though three groups of researches are specifically referred to as the grounds for the award of the medal this year to Dr. Wright, the Council is not unmindful that this award is a recognition of the work of a lifetime devoted to astronomy.

The whole of Dr. Wright's astronomical career has been associated with the Lick Observatory, of which he became Director in 1935, on the retirement of Dr. Aitken. It is difficult to assess how much the Observatory has been indebted to Dr. Wright for his skill in design and for his ability to get the best possible results out of any equipment; but the debt is not a small one. When as a young man he joined the staff at the Lick Observatory, the application of photographic methods to spectroscopic observations was in its infancy, and the accidental and systematic errors of such observations were relatively large. One important source of error was flexure; it was customary then for spectrographs to be attached to the telescopes by, and supported entirely from, their upper ends. The original Mills spectrograph at the Lick Observatory had an improved method of support, which greatly reduced flexure. But it was Dr. Wright's suggestion that the spectrograph should be supported near its two ends, like a bridge truss, with a form of support such that any strains generated in the truss system cannot cause corresponding strains in the spectrograph, that enabled flexure troubles to be almost entirely eliminated. This type of support was adopted for the new Mills spectrograph at Mount Hamilton and for the Chile spectrograph, and is now universally used. The enclosure of the entire spectrograph in a tight-fitting box, lined with thick hair-felt, on whose surface resistance wires were placed for heating and temperature control was another improvement due to Dr. Wright. His also was the device for sending the light from two comparison-spectrum sources through two small totally reflecting prisms, whose slightly separated edges define the length of the slit, to enable the comparison spectrum to be thrown in as often as is desired, without interruption to the exposure on the star spectrum.

To illustrate Dr. Wright's genius for the design and adjustment of apparatus, the following incident may be mentioned. Nova Persei was discovered in 1901 at a time when much of the spectrographic equipment of the Lick Observatory had been shipped to Sumatra for eclipse observations. It was desired, *inter alia*, to obtain high dispersion photographs

of the *D* region. The Mills spectrograph was limited to portions of the blue and violet, and to obtain the desired observations, the construction of another prism box and some auxiliary apparatus was necessary. Designs of a prism box to hold three dense 60° prisms were prepared by Dr. Wright, the box was constructed of wood by the Observatory carpenter, and the entire apparatus was adjusted and tested by Dr. Wright, the whole work being done in a day and a half. No effects of flexure were detected in long exposures.

When Dr. Campbell prepared his plans for an expedition to Chile, for the determination of the radial velocity of southern stars that could not be observed from the Lick Observatory, Dr. Wright was selected to take charge of the expedition. As this was the first serious attempt to measure stellar velocities with a large Cassegrain reflecting telescope, which involved many radical departures from conventional forms, it was decided by Dr. Campbell to erect the telescope on the top of Mount Hamilton and to take some spectrograms to ensure that everything was in correct order. But an unfortunate error in figuring the 36-inch mirror was made by the opticians, and it became necessary to return both principal and secondary mirrors for refiguring. Delay was caused, the equipment had eventually to be dispatched without any testing, and the expedition reached its destination at Santiago, Chile, just at the beginning of the rainy season, the very time that it had been hoped to avoid. But this was not the end of the difficulties. To quote from Dr. Wright's account of the expedition:

"Unfortunately the day of our arrival in Valparaiso (1903 April 18) marked the outbreak of an extended strike of launch hands, that culminated a month later in a most serious riot, in which a number of business buildings were burned, and over a hundred men were said to have been killed in the streets. During this interval of a month and over, practically no merchandise could be unloaded from lighters, nor moved in the Custom House, nor along the water front. Most of our belongings were unloaded into lighters and left to bob around on the bay. I was fortunate enough, however, to be able to get the mirrors of our telescope, weighing with their packing some nine hundred pounds, into, or rather across the gunwales of a passenger rowboat, and thus balanced we rowed them gently to the shore."

The buildings for the Observatory were eventually commenced on May 27, and the whole installation was completed by September 11, when observations were commenced. To appreciate what this involved, we must remember that this was the rainy season and that the first assembling and testing of the complete equipment was on a mountain top, away from instrument makers and machine shops. Dr. Wright remained in charge of the expedition until 1906 March 1, when he returned to Mount Hamilton. During this time, spectra of 250 bright stars, south of $-30°$ declination, were photographed. 150 stars, with measurable lines, were selected for further observation, and several spectrograms of each star were obtained. 41 of these stars were observed to have variable radial velocity.

Before giving an account of Dr. Wright's work on the spectra of the gaseous nebulæ, it seems desirable to recall briefly what was known about

these spectra before the results of Dr. Wright's investigations were published. Only by doing so can we fully appreciate the importance of the contributions that he has made to this subject.

The first spectroscopic examination of a nebula was made by Sir William Huggins in the year 1864. In the preceding years many nebulæ had apparently been resolved by Lord Rosse's great reflector into innumerable stars, and the opinion was gaining ground that all nebulæ might be merely aggregations of stars. On the evening of 1864 August 29, Huggins directed his telescope to a planetary nebula in Draco. Here is his own account of this memorable observation :

"I looked into the spectroscope. No spectrum such as I expected! A single bright line only! At first I suspected some displacement of the prism, and that I was looking at a reflection of the illuminated slit from one of its faces. This thought was scarcely more than momentary ; then the true interpretation flashed upon me. The light of the nebula was monochromatic, and so, unlike any other light I had as yet subjected to prismatic examination, could not be extended out to form a complete spectrum. . . . A little closer looking showed two other bright lines on the side towards the blue, all the three lines being separated by intervals relatively dark. The riddle of the nebulæ was solved. The answer, which had come to us in the light itself, read : Not an aggregation of stars, but a luminous gas."

The three lines observed by Huggins were the two green lines, commonly denoted by N_1 and N_2, together with the hydrogen line $H\beta$.

There was controversy for many years about the identification of the two principal nebular lines, N_1 and N_2, a controversy which would not have persisted for so long, if it had been possible to measure their wave-lengths accurately. The first accurate measurements were those of Keeler in 1891, using a visual spectroscope attached to the 36-inch refractor at the Lick Observatory ; he was able to conclude that these two lines are not represented in the solar spectrum by any absorption lines sufficiently strong to appear on Rowland's photographic map.

The most extensive observations of nebular wave-lengths, before those made by Wright, were made by Campbell, who investigated both visually and photographically the spectra of the Orion nebula and of 6 planetary nebulæ in the years 1893 and 1894. A number of new lines were discovered and their wave-lengths determined with rather low accuracy. Campbell showed that several of the lines coincided in position with lines in the spectra of the Orion stars.

But for some time, with the exception of the lines due to hydrogen and helium, little progress was possible in the identification of the nebular lines. The principal lines, N_1 and N_2, were attributed to a hypothetical element "nebulium." Buisson, Fabry and Bourget in 1914 applied interference methods to the Orion nebula and determined accurately the wave-lengths of the doublet near λ 3727 ; they concluded that the probable value of the atomic weight of the unknown gas that emitted these lines was in the neighbourhood of 3, and that the green lines were emitted by a gas of lower

atomic weight. Theoretical investigations by Nicholson suggested that many of the lines were due to atoms with a nuclear charge $+4e$ with one ring of four electrons when in the neutral state. It was believed at that time that unknown elements of low atomic weight might exist and that there might be, for instance, two unknown elements of atomic weights approximating to 2 and 3 between hydrogen and helium. The work of Moseley and the conception of atomic number were shortly afterwards to prove conclusively that there were no gaps in the series of atomic numbers belonging to the known light elements. The lines of nebulium and the other lines of unknown origin, whose presence in the spectra of gaseous nebulæ had been established, must therefore be due to known elements, but possibly under conditions that had not been reproduced in the laboratory.

Dr. Wright's first observations of the spectra of the nebulæ were made in 1902 for the purpose of determining more accurately the wave-lengths of some of the brighter lines, the best values at that time being uncertain by about one-tenth metre, in order to investigate whether there was any relationship between the positions of the nebular lines and the positions of certain features of the bands in Nova Persei 1901. He had planned to extend this investigation to the fainter lines, but he was required to take charge of the D.O. Mills Expedition to Chile. After his return to the Lick Observatory other work claimed his attention, so that it was not until about ten years after the earlier observations that work on the nebulæ could be resumed.

As the work progressed, its scope was extended. The original purpose was the accurate determination of the wave-lengths of the nebular radiations. A variety of spectrographs were used, some of high and some of low dispersion, and one series of plates was obtained with a grating. The observations as first planned had been substantially completed in the summer of 1914, when it was noticed that on a plate exposed on N.G.C. 6572 for 13·6 hours the radiation of wave-length λ 4686 from the centre of the nebula was a broad bright band with a width of about 15 A. In the spectra of the nebulæ this radiation normally appears as a narrow line, whilst in the spectra of the Wolf-Rayet stars it is a broad band, a feature that it shares in common with other radiations from these stars. This observation suggested the investigation of the spectra of other nebular nuclei. For this purpose, great care is necessary in making the observations. It is customary when photographing stellar spectra to allow the image to drift along the slit of the spectroscope, in order to lengthen the lines so as to facilitate their measurement. To follow this procedure in the case of the nucleus of a planetary nebula would give a blend of the spectrum of the nucleus and of that of the surrounding nebulosity. By following the nucleus very accurately and not allowing it to drift, Dr. Wright was able to obtain satisfactory photographs of the spectra of the nuclei of a number of planetaries.

One outcome of this extended investigation was some interesting information with regard to the localisation of lines in some of the nebulæ. Unknown to Dr. Wright, this phenomenon had already been observed by Max Wolf in the year 1908 in the Ring Nebula in Lyra. Wolf took successive

exposures on this nebula with the slit of his spectrograph in different position angles, obtaining a series of monochromatic images. He found the λ 4686 ring to be the smallest and the λ 3727 ring to be the largest. The results obtained by Dr. Wright suggested the desirability of extending his investigations still further, so as to study the distribution of intensity, in different radiations, throughout the nebulæ. This can most conveniently be done with the aid of a slitless spectrograph. In the case of objects of small angular dimensions with bright line spectra, such as the planetary nebulæ, the slitless spectrograph will give a series of discrete images without undue overlapping.

At about this time Dr. Wright was occupied with the redesign of a quartz spectrograph for use in the prime focus of the Crossley reflector. He therefore modified the design so that the spectrograph should serve a double purpose and be capable of use either with or without a slit. This spectrograph illustrates Dr. Wright's skill and ingenuity in design. It has two 2-inch quartz prisms of the Cornu type, with simple quartz lenses. The prisms are set for minimum deviation at λ 3600 and there is a field of good definition, though necessarily strongly curved, extending from λ 3000 to λ 5000. The case was made of aluminium, being very rigid though light. The weight of the complete spectrograph, including the accessories for the control of the temperature, was only 40 lbs., so that the spectrograph just balanced the double slide plate-holder used for direct photography in the prime focus. The spectrograph intercepted relatively little light from the 36-inch mirror. For use without a slit, the collimator was removed and a concave lens was substituted to give a parallel beam. This spectrograph in its slitless form proved a most efficient instrument for the investigation of the distribution of intensity in different radiations, giving monochromatic images from the ultra-violet to $H\beta$ with practically the same faithfulness to detail that is obtained in a direct photograph.

Intensities were assigned to the various radiations present in each spectrum. This work was done before the development of rigid spectrophotometric methods. The image densities obtained with the quartz spectrograph were measured against a calibrated wedge, and corrections for atmospheric absorption were applied to reduce to the zenith. Intensities measured on strong and weak plates of each nebula were combined. Intensities were also assigned to the spectra obtained with the single glass prism spectrograph, but on the rather more arbitrary basis that had been used in his earlier observations. It was recognised by Dr. Wright that the assigned intensities left much to be desired in the way of accuracy. Yet they were a great advance on any system of intensities that had previously been used for the nebular lines. Some of the uncertainties in the final system of intensities are inherent in the observations ; images in different radiations are of different sizes and shapes, and the variations of intensity over the image in one wave-length are different from those over the image in another wave-length. In dealing with so wide a range of wave-length, different types of emulsions, with widely differing characteristics, were employed and their co-ordination and combination presented difficulties.

For the visible region of the spectrum, the plates were bathed in pinacyanol, pinaverdol and homocol.

The results given in Part 6 of vol. 13 of *Lick Publications* comprise 70 lines from λ 3313 to λ 6730. Thirty of these had not previously been observed. At the long wave-length end, the observations were extended a little later to λ 7325 by the employment of plates bathed in dicyanin. The limit on the short wave-length side was determined by the falling off in reflectivity of a silver film in the extreme ultra-violet. When the process of coating a glass mirror with a film of aluminium by vacuum distillation was developed, the 36-inch mirror of the Crossley reflector was the first large mirror to be coated. As is well known, the reflecting power of the aluminium film does not drop appreciably in the extreme ultra-violet, and Dr. Wright was not slow to take advantage of this to extend the investigation of the nebular spectra to the extreme limit possible, where, because of ozone absorption in the upper atmosphere, the atmosphere becomes opaque.

Some interesting results with respect to line distribution were obtained. It was found that the distribution of intensity was very different from one radiation to another. The image given by λ 3426 was equal to or smaller than that given by any other radiation. That given by λ 3727 was always at least as large as, and usually larger than, any other image. The general order of increasing size was 3426, 4686, the *H* lines, 3869 and 3727. In the early stages of the investigation it appeared possible that the observed distribution might be the result of gravitational action. But the fuller evidence did not support this view ; the line λ 3727, for instance, was found to tend to concentrate in the exterior condensations, and the distribution of helium as indicated by the line λ 4471 showed a decided difference from that indicated by the line λ 4686. Dr. Wright concluded that it was a physical condition that was localised, rather than actual material, but that the differences in the various images might be related to some extent to inhomogeneities in composition and to selective absorption. Consideration of the behaviour of the various lines led to the conclusion that certain pairs or groups of lines were, with more or less certainty, linked.

The rapid development during recent years in the theory of atomic spectra has enabled all the lines observed by Dr. Wright, with few exceptions, to be identified and has provided a fairly complete picture of the mechanism of the production of the lines and of the physical conditions existing in the nebulæ. This interpretation has been in large measure based upon a knowledge of accurate wave-lengths, of the relative intensities of different lines and of the differences in line distribution ; for this knowledge we have been dependent in very large measure upon Dr. Wright's observations.

Though it may be regarded as beyond the scope of the present address, I think that a brief account of this interpretation is not altogether out of place here, because it enables us better to appraise the value of Dr. Wright's investigations.

The planetary nebulæ show the complete spectrum of hydrogen with great intensity and usually, but with much lower intensity, the spectrum

of neutral helium. The lines of ionized helium may be present in great strength, weak or absent, depending upon the temperature of the central star. With the exception of some lines of carbon, nitrogen and oxygen, the remaining lines are so-called "forbidden" lines of neon, argon, nitrogen, oxygen and sulphur. Some of these forbidden lines are amongst the strongest in the spectra ; such lines, for instance, as the N_1, N_2 lines, which are due to doubly ionized oxygen ; the lines at $\lambda\lambda$ 3868, 3967, due to doubly ionized neon ; the lines at $\lambda\lambda$ 3726, 3729, due to ionized oxygen ; and the lines at $\lambda\lambda$ 3346, 3426 due to neon atoms which have lost four electrons by ionization. The association of these pairs of lines was pointed out by Dr. Wright.

The principal features of the spectra of the planetary nebulæ that demand explanation are the presence of certain permitted lines of oxygen and nitrogen, and the absence of other lines, some of which are stronger lines in laboratory spectra ; the great strength of many of the forbidden lines, which have not been observed in laboratory spectra ; and the differences in line intensity distribution.

We consider a model consisting of a star of very high temperature, which therefore radiates strongly in the extreme ultra-violet, surrounded by a gas or nebula of very low density, of the order of 10^{-18}. The nebula consists largely of hydrogen, but contains a smaller amount of helium and only traces of oxygen, nitrogen, neon, argon, carbon, sulphur and possibly other elements.

The atoms of the nebula take up the extreme ultra-violet radiation from the central star and transform it into radiations of longer wave-length, including some in the visual and photographic regions. It is by the emission of this transformed radiation that the nebula becomes visible to us. Let us consider the mechanism of this process in the case of hydrogen, which is the most abundant element present in the nebula. The hydrogen atom has one electron, which can exist in any one of a large number of states, the most stable of which is the state of lowest energy. Suppose an atom is in this state. If radiation falls on the atom, of exactly the wave-length that the atom would emit when the electron falls from a state of higher energy to this state of lowest energy, a quantum of energy of this wave-length will be absorbed and the electron will be raised to the corresponding state. Radiation of wave-length λ 912 will raise the electron to the highest possible state. If radiation of shorter wave-length, and therefore larger quanta of energy, falls on the atom, the atom will be ionized and the energy in excess of that required to expel an electron will be carried away as kinetic energy of the expelled electron. With a star of very high temperature, having a strong emission of energy in the extreme ultra-violet, this process will be the one by which most of the primary continuous radiation is absorbed.

Sooner or later, the hydrogen ion that has been ionized in this way will pick up another electron and will return to the state of lowest energy by a series of jumps through intervening states ; the first jump will normally correspond to the emission of one of the lines in the Balmer series, but the

last jump will always correspond to the emission of one of the lines in the Lyman series, between λ 911 and λ 1216. Radiations of these frequencies are, however, the radiations that the hydrogen atom will absorb strongly, raising the electron to a higher state, from which it may descend again by one or more jumps. If the last jump is from the state next to that of lowest energy, radiation of wave-length λ 1216 will be emitted. Should this be absorbed again, it can only lead to remission of the same line. Thus, with successive absorption and re-emission of quanta of energy, there is a gradual transformation of energy into quanta of wave-length λ 1216. The concentration of this radiation within the nebula therefore becomes very great.

By an exactly similar process, ionized atoms of helium—which, like the hydrogen atoms, have each only one electron—can absorb energy below wave-length λ 228. This energy is converted into radiation in the visible and ultra-violet regions, together with a concentration of radiation in the far ultra-violet of wave-length λ 303·78. It may be noted that in order that there may be a plentiful supply of energy of shorter wave-length than λ 228, the temperature of the central star must be very high. This explains why in the spectra of some planetaries the lines of ionized helium are of great intensity, whereas in the spectra of others they are extremely weak.

The sequence of events is rather more complicated for the atoms of helium, but it can be shown that the final result is the emission of radiations of wave-lengths λλ 601 and 625.

These extreme ultra-violet radiations given out by the atoms of hydrogen, neutral helium and ionized helium can in turn excite radiation in atoms of other elements by similar processes. If any atom should happen to have an energy difference between two states corresponding to quanta of energy of any one of these radiations—which, as we have seen, will be very numerous within the nebula—the radiation will be absorbed by the atom. By chance, there is such a correspondence for doubly ionized oxygen. The energy difference between the state of lowest energy and the state of higher energy, known as the $3d^3P_2$ level, corresponds to radiation of wave-length λ 303·80. The extreme ultra-violet radiation, λ 303·78, emitted by the atoms of ionized helium, will therefore be readily absorbed by any doubly ionized oxygen atoms, raising them to the $3d^3P_2$ state. From this state they can fall back to the ground state either directly, by re-emission of radiation of the same wave-length, or in a series of steps leading to the emission of radiations of wave-lengths λλ 3025, 3047, 3133, 3299, 3341, 3429, 3444 and 3759 together with radiation in the extreme ultra-violet of wave-length λ 374·44. With the exception of the first two lines, which were beyond the limit of wave-length reached by Dr. Wright, it was just these lines, and only these lines, in the spectrum of doubly ionized oxygen—the permitted lines only being under consideration at present—that were found by Dr. Wright to be present in the spectra of the planetary nebulæ.

By another unexpected coincidence, the radiation of wave-length λ 374·44, which is finally emitted in the mechanism just considered, is in almost exact agreement with the wave-lengths of the radiations given out

by doubly ionized nitrogen atoms when they fall from the $3d^2D_2$ or the $3d^2D_3$ states to the $2p^2P_2$ state. This energy will therefore be strongly absorbed by such atoms and the subsequent transitions lead to the emission of radiations of wave-lengths λλ 4097, 4103, 4634, 4641, 4642 ; these are the only permitted lines of doubly ionized nitrogen that Dr. Wright observed in the spectra.

It may be noted that although the radiation of wave-length λ 303·78, which is absorbed by the doubly ionized atoms of oxygen, and that of wave-length λ 374·44, which is absorbed by the doubly ionized atoms of nitrogen, may also be partially used to ionize atoms of hydrogen or neutral helium, the latter process has a much lower absorption coefficient. The very small abundance of both oxygen and nitrogen in the nebulæ accounts for the absence of most of the permitted lines in their spectra ; but the readiness with which radiations of the special frequencies referred to are absorbed accounts for the high intensity that can be attained by the few permitted lines that are produced by the special mechanism described above. In confirmation of the reality of these mechanisms, it may be mentioned that the permitted lines of both oxygen and nitrogen should be absent if the spectrum does not show lines of ionized helium. This is in agreement with Dr. Wright's observations.

We remarked above that any energy absorbed by an atom of hydrogen, in excess of the amount required to ionize it, is carried away by the ejected electron as kinetic energy. This energy may be given up in exciting radiations in other atoms. But, inasmuch as most of these electrons have less than 10 electron volts of energy, which is insufficient to raise the hydrogen atom from its state of lowest energy to the state of next higher energy, this energy will not be given up to any great extent to the atoms of hydrogen, in spite of the great predominance of that element. But there are other atoms that have states whose energy is less than 10 electron-volts above the state of lowest energy. These atoms are principally those with 6 electrons, viz. C, N^+, O^{++}, F^{+++}, Ne^{++++}, with 7 electrons, viz. N, O^+, F^{++}, Ne^{+++}, or with 8 electrons, viz. O, F^+, Ne^{++}. Now the particular states in question are what are termed metastable states, or states with low transition probabilities. In other words, an atom will remain in one of these states for a long time, of the order of from a second to several hours, before it returns to the normal state with the emission of radiation. These times, which depend upon the particular atom and state considered, may be compared with the times of the order of 10^{-8} seconds, for which an atom will remain in the ordinary states. In terrestrial sources, and also in most astronomical sources, each atom is struck by other atoms thousands or even millions of times a second, and the effect of these collisions may be either to drop the atom to the lower state, the energy difference being used to increase the kinetic energy of the colliding atom, or to raise it to a higher state by taking kinetic energy from the colliding atom. The atoms in such sources that are in metastable states are therefore knocked out of them before they can radiate the wave-lengths corresponding to the transitions from those states. Lines produced by atoms dropping from a metastable state to a lower state

are termed "forbidden" lines; these lines are not observed in laboratory spectra.

In a nebula, the density is so low that collisions are few and far between, occurring for a given atom at average intervals of several hours or days. Any atom in one of these special states has a very high chance of dropping to a lower state, with the emission of the forbidden lines. Since, moreover, there is a large supply of electrons with the appropriate kinetic energy, for which almost the only outlet is the excitation of these forbidden lines, it is possible for these lines to be extremely strong in the spectra, although the abundance of the elements concerned is very small.

In this way Bowen has satisfactorily accounted for the principal features of the spectra of the planetary nebulæ, as observed by Dr. Wright.

There remains the observed differences in line distribution to be considered. In a general way the observations can be summed up in the statement that the smallest images correspond to the most highly ionized atoms and the largest images to the least ionized atoms. The smallest observed images are normally those of Ne^{++++} at λ 3426 and of O^{+++} at λ 3346. The largest is normally that of O^{+} at λ 3727. Bowen has qualitatively explained this in the following way. He assumes a central star of very high temperature, say 150,000°, and supposes it to be surrounded by an atmosphere of oxygen of very low density. The intensely strong radiation in the extreme ultra-violet will not permit the atoms in the near vicinity of the star to exist in a state of ionization lower than O^{++++}. Whenever an electron unites with such an atom, with the emission of one or more lines in the O^{++++} spectrum, it is almost immediately shot out again by the absorption of radiation of wave-length shorter than λ 160. There will be a shell around the star within which the absorption of such radiation will be complete, so that only radiation of longer wave-length will pass outside this shell. Outside this shell, O^{+++} atoms can exist and by similar reasoning there will be another shell within which the O^{+++} spectrum is produced and the radiation between λ 160 and λ 225 is absorbed. The next shell will give the O^{++} spectrum, with absorption of the radiation between λ 225 and λ 353; and so on. The presence of atoms of other elements will make the actual conditions more complicated, but, in a general way, it can be seen that the diameters of various images should increase with the decrease of the corresponding ionization potentials. Incidentally, it is to be noted that the size of the image of the λ 4686, He^{+}, line is about the same as the size of the images given by the permitted lines of O^{++}, as would be expected from the theory of the production of these lines that we have described.

These investigations led Dr. Wright to a further conclusion of great importance—that the nuclei of the planetary nebulæ were Wolf-Rayet stars. It may be said with truth that both Pickering and Keeler nearly thirty years earlier had drawn attention to resemblances between the spectra of planetary nebulæ and of Wolf-Rayet stars and that, in the Harvard work on stellar classification, the two groups of objects have been classed together. Pickering based his statement on certain correspondences in wave-lengths of lines, which we know now to be lines of hydrogen and helium, and on a similarity

of distribution in the sky. The important question of breadth of the line was not mentioned. Keeler's conclusion was based largely on the increased breadth and haziness of the faint helium D_3 line and other nebular lines of N.G.C. 6572 on crossing the spectrum of the nucleus. This particular observation was not confirmed by the later observations of Campbell. Dr. Wright's investigations have shown that the broadening out of a line in passing from the nebula to the nucleus, though occasionally observed, is rare. It is, in fact, unusual to find a given radiation present both as a nebular line and as a nucleus band in the same object. There is very little resemblance between the spectrum of a nebula and the spectrum of its nucleus : the two spectra are quite distinct.

It was because of this difference between the spectra of the nebula and the nucleus that Campbell, after a detailed investigation of the spectra of the Wolf-Rayet stars, came to the following conclusion : "For the present, at least, this type of spectrum (*i.e.* the Wolf-Rayet type) must be considered as distinct from every other known type, just as the nebular spectrum is distinct, and, like the nebular spectrum, containing lines whose origin cannot be assigned."

At the time of Dr. Wright's investigations, therefore, the relationship between the nebulæ and Wolf-Rayet stars was obscure. A relationship had been suspected, but nothing conclusive had been proved and Campbell's work appeared to negative the existence of any relationship. It was not until the spectrum of the nucleus was isolated from that of the surrounding nebulosity that the true relationship became clear. Of 30 nebular nuclei examined by Dr. Wright, 15 gave spectra of the typical Wolf-Rayet type ; the remaining 15 nuclei gave a continuous spectrum only, in which no broad bands were visible. A characteristic of all the spectra was a great extension into the ultra-violet. Dr. Wright's conclusions were summed up as follows :—

"As we have already seen, the invariable characteristic of the nucleus spectra is the remarkable extension into the ultra-violet. The class O spectra show this peculiarity in only a slightly less marked degree, some of them matching up perfectly in this respect with the nebular nuclei. I cannot but believe that this wonderful richness in ultra-violet light which gives to the spectra of nebular nuclei their characteristic appearance, in spite of the great difference which they exhibit in the matter of bright bands, is the dominating peculiarity which must be regarded as the distinguishing mark of this group of objects. As it is also characteristic of the class O stars, and since half of the nuclei are undoubtedly stars of that class, I have no hesitancy in advancing the opinion that the nebular nuclei belong to the same general division as the class O stars, irrespective of whether they exhibit bright bands or not. But, however we label them, the really significant thing seems to be that these objects present a type of energy curve which, if we interpret it in the usual way as a heat phenomenon, marks them as bodies of very high temperature, higher probably than that of any other class of stars." To fit the energy distribution curve in the ultra-violet to the Planck radiation formula, Dr. Wright found that it was necessary to assume a

temperature of the order of 50,000° C., which, he remarked, seemed absurdly high. With the fuller knowledge of to-day, we see nothing absurd in such a conclusion. We know also how fully Dr. Wright's carefully drawn conclusions have been substantiated by the later study of the Wolf-Rayet stars by J. S. Plaskett and Beals, and how the high temperatures of the nuclei have been confirmed by the work of Zanstra.

We have mentioned that Dr. Wright's first observations of planetary nebulæ were made in connection with the discussion of spectra of Nova Persei 1901. Novæ have claimed a good deal of his attention. It is not, perhaps, without significance that the two classes of celestial objects in which Dr. Wright has been most interested have some close relationships. The spectra of novæ in their later stages have strong resemblances to the spectra of Wolf-Rayet stars. Several novæ, subsequent to their outburst, have been observed to be surrounded by nebulosity, whose growth can be measured. In this stage, the similarity to the planetary nebulæ is very marked. On the other hand, the nuclei of planetary nebulæ are Wolf-Rayet stars. In one nebula, the Crab nebula, the outward movement of matter has been measured, and it seems not improbable that in this nebula we see a nova many years after its outburst. There are also ex-novæ and Wolf-Rayet stars around which no nebulosity can be observed. Nevertheless, the current theory of Wolf-Rayet stars supposes that there is a continuous ejection of matter from them. Whether all Wolf-Rayet stars are ex-novæ and whether all novæ eventually become Wolf-Rayet stars are questions to which no definite answer can yet be given.

The observation of novæ is essentially a task for the co-operation of many observatories. The complexity of the spectra of most novæ in their earlier stages necessitate for their proper interpretation the use of spectrographs of widely differing dispersive powers, covering between them as great a spectral range as possible—from the extreme ultra-violet to beyond *Hα* in the red. Great changes in the spectra can occur so rapidly—even in novæ of relatively slow development—that it is impossible for any single observatory to obtain a complete record of them. If one nova could be caught as its outburst was beginning and a complete record of its subsequent development obtained by the co-operation of many observatories, and if this complete material could finally be placed in the hands of one person for discussion, there would be hopes of obtaining a much clearer insight than we have at present into the phenomena of a nova outburst. At present, however, it is by the accumulation of facts about as many novæ as possible and by the comparative study of these facts that further insight into the problem must be obtained.

These two essentials—the accumulation of facts and their comparative study—have been the guiding principles in Dr. Wright's work on novæ. I do not propose to give any detailed account of this work to-night, for I do not think that any purpose would be served by doing so. The present views about novæ have developed gradually as the result of the work of many astronomers. As more and more observations have accumulated, the point of view has gradually changed. Developments in the theory

of atomic spectra have led to the identification of most of the lines that have been observed in novæ in the nebular stages and have facilitated the interpretation of what is happening. Characteristic of Dr. Wright's work has been the refusal to jump to premature conclusions on evidence that has not appeared to be fully conclusive and emphasis on any features that appear to be abnormal or not to be in accord with current theories.

Two instances may be mentioned. It is generally accepted that the displacements found in the spectra of novæ vary directly with the wave-length and can be interpreted in terms of the Doppler effect. There is theoretical support for this interpretation. But although sometimes the evidence in support of the proportionality between displacement and wave-length is strong, in many cases the available range of wave-length is not sufficient to distinguish between this and other possible laws. Dr. Wright has drawn attention to one instance in which, with a spectral range from $H\pi$ to $H\alpha$ (λ 3691 to λ 6563) available, the displacements deviated considerably from the Doppler law. He remarks that in this case the displacement might be a Doppler effect modified by something else. It is well that attention should be given to such exceptional instances when there is a tendency to generalize on the basis of evidence that is not fully conclusive. Such generalizations are often accepted by later investigators without critical examination.

The second instance concerned the so-called stationary lines of calcium in Nova Ophiuchi 1919. It was generally supposed that these lines were produced by a calcium medium "at rest in space." In the spectrum of Nova Ophiuchi the positions of these lines differed by the large amount of one-third of an angstrom from the positions to be expected on the "at rest in space" hypothesis, showing, as Dr. Wright pointed out, that the calcium cloud was not at rest. Bearing in mind Plaskett's subsequent discovery that the interstellar clouds share in the general rotation of the galaxy, the positions of the interstellar calcium lines in Nova Ophiuchi can be satisfactorily accounted for by galactic rotation and the great distance of the nova.

A feature of particular interest in some novæ has been studied in detail by Dr. Wright. This feature he terms the "4640" phase. It is normally interposed between the bright band phase that follows the maximum brightness and the nebular phase: in this phase broad bands near λ 3484, λ 4100 and λ 4640, due to N^{++}, are prominent features of the spectrum. These bands are normally structureless, with ill-defined edges, but they usually become sharply defined as the nebular spectrum develops. In Nova Geminorum 1912 there were several recrudescences of the "4640" phase after the nebular phase had been entered upon. The nebular bands were of normal structure and width. When a reversion to the 4640 phase occurred, the N^{++} bands at $\lambda\lambda$ 3484, 4100, 4640, together with a band of unknown origin at λ 3412, flared out into broad ill-defined bands, whilst at the same time the λ 4686 band of He^{+}, which had been strong, disappeared, as well as bands at $\lambda\lambda$ 3445 and 3760. These bands are presumably the permitted radiations of O^{++}, which appear in the planetary nebulæ. The

flaring of the ionized nitrogen bands was accompanied or preceded by a brightening of the star ; Dr. Wright is careful to remark that, as the brightness of the star was continually fluctuating, this correspondence may be quite accidental. We have here something that involves the λ 4686 line of ionized helium, together with permitted radiations of doubly ionized nitrogen and oxygen, suggesting some connection with the mechanism by which these permitted lines appear in the spectra of the planetary nebulæ. Bowen has remarked that as the end-product of the chain of transformations involved is the emission of ultra-violet radiation of wave-length λ 452 and as no absorption line is known that can remove energy of this wave-length, its radiation density may build up to very high values. He suggests that the high radiation pressure of radiation of this wave-length on the N^{++} atoms may be the cause of the "blowing up" of the nitrogen in a nova, which is indicated by the sudden flaring of the lines. This suggestion does not account for the simultaneous disappearance of the λ 4686 line of He^{+} and of the O^{++} lines at λλ 3445, 3760. Conditions in a nova are more complex than in a planetary nebula, and the complete explanation of the "4640" phase, as of many other nova phenomena, still remains obscure.

A further complication in the λ 4640 phase was observed by Dr. Wright in Nova Aquilæ 1918. In the spectrum of this nova, the normal configuration of the bands showed two bright maxima situated nearly centrally upon them. When the flaring of the λ 4640 and associated bands occurred, the λ 4686 He^{+} band disappeared as usual, except that the central pair of maxima persisted, apparently unaltered. As the phenomenon repeated itself at each flaring up, it was evidently due to some definite condition in the star, suggesting possibly that the two bright maxima are emitted under special physical conditions or that they may originate in a different part of the star from that in which the nitrogen lines originate. Bearing upon this possibility, Dr. Wright found from slitless spectrograms that the size of the nebulosity around the nova, as photographically recorded, was different in different images and that different parts of an emission band came from different parts of the nebula. Observations with a slit spectrograph by Moore and Shane gave further information about this latter feature and showed that the two bright maxima of the bands, which in the case of the λ 4686 line did not disappear when the flaring of the nitrogen lines occurred, were localized at the top and bottom of the bands and therefore originated a long way from the central star.

It was found that the principal nebular lines, N_1 and N_2, in slitless spectrograms of Nova Aquilæ 1918 gave large images, the λ 4363 line gave an image of intermediate size and the hydrogen images were small. If we interpret, as is now generally done, the breadth of the emission bands as an effect of velocity in the line of sight in an expanding nebulosity, the breadths of the various lines correspond to a uniform rate of expansion, so that the size of the images should be the same for all bands. A few years later, in 1922, two bright ends were practically all that remained of each band. These were offset from the continuous spectrum of the star, showing that they originated in the surrounding nebulosity. In the strong

continuous spectrum, extending far into the ultra-violet and indicative of the very high temperature of the star, the radiation of ionized helium, λ 4686, was shown ; this occupied its normal position and did not extend either above or below the continuous spectrum. As in the case of the planetary nebulæ, this indicates that the nucleus has the characteristics of a Wolf-Rayet star.

I have referred in some detail to these points mainly because, though a satisfactory explanation of the broad features that follow a nova outburst can now be given, there are many features whose explanation is still obscure and special attention has at one time or another been called to these by Dr. Wright.

The third ground for the award of the gold medal to Dr. Wright was his work on the photography of planets in different colours. It is not necessary for me to give any detailed account of this work because an excellent résumé was given a few years ago by Dr. Wright himself before this Society, in the George Darwin lecture. It is possible that these observations were suggested by the results that followed the application of the slitless spectrograph to the planetary nebulæ, when images in different monochromatic radiations were obtained. The following quotation from the George Darwin lecture suggests a continuity of thought between the work on the planetary nebulæ and the work on the brighter planets :

"(The methods employed) occupy ground between precise spectroscopy on the one hand and the more versatile means of analysis provided through the perception of form and colour by the eye on the other. The spectroscope is by far the most powerful and accurate instrument that exists for the study of radiation, but while its indications are, in a sense, absolute, they do not in general, or without the multiplication of observations, give information relating to form and distribution. While supplying these deficiencies, the evidence provided by the eye requires for its interpretation knowledge derived from other sources. A series of photographs taken with approximately homogeneous light of distinct spectral regions has an advantage over the coloured presentation provided by ordinary visual perception in that its several images are separate, but its testimony, like ocular evidence, must be interpreted in the light of independently derived knowledge."

Though photographs of the planets in light of different colours had been obtained by several other investigators some years before Dr. Wright's work, none of these earlier observations had been so comprehensive as those of Dr. Wright, nor had the evidence that they provide about the conditions on the planets been so carefully studied. Dr. Wright was one of the pioneers in the use of plates, sensitised with kryptocyanine, for terrestrial photography in the infra-red, and, by the employment of such plates, he was able to extend the mean wave-length in which the planets were photographed to λ 7600. The limit in the ultra-violet direction was about λ 3600.

The photographs of Mars showed conclusively that the planet was surrounded by an atmosphere of considerable depth, estimated to be of the order of 60 miles, of appreciable absorbing and light-scattering power.

This atmosphere seems to be, for all the colours considered, much more opaque than the Earth's atmosphere. Two types of temporary markings, called for convenience clouds, were studied. The one type appears on the photographs in ultra-violet and blue light, but not on those in red or infra-red light. The other type shows the converse behaviour. The former are tentatively suggested to be clouds of fine haze, high up in the atmosphere and having relatively great light-scattering power. The latter are identified with the yellowish marking sometimes seen in visual observations, and it is suggested that they are clouds of aqueous vapour, low down in the atmosphere and appearing yellow because of atmospheric absorption. The polar caps are proved to be in large measure an atmospheric phenomenon; there appears to be an atmospheric cap, in the form of a cloud or aggregate of finely divided material, presumably condensed out of the upper atmosphere. There is evidence also of a low cap, apparently resting on the planet. Dr. Wright is careful to emphasise that some of these conclusions are tentative. He remarks that "In reality what the subject needs is not speculation but more data of observation, but it is not always easy in reconnoitring to refrain from straying from the pavement of positive knowledge for an adventure on the stepping-stones of conjecture."

The conclusions drawn from the photographs of Jupiter and Saturn are even more tentative, for it is not possible in the infra-red photographs to see the surface of the planet. The photographs in different wave-lengths probably represent different levels in the atmosphere, and the photographs in the infra-red and ultra-violet show very marked differences. The red spot, for instance, gradually fades as the wave-length of the colour increases. Such phenomena as the irradiating white spot and the great disturbance in the southern hemisphere of Jupiter, observed by Hargreaves, Peek and Phillips in the late summer and autumn of 1928, and the white spot on Saturn, discovered by Will Hay in 1933, have been studied by Dr. Wright by means of photographs in different colours. These photographic observations form a valuable addition to the visual observations. Planetary observers, though they may not be in entire agreement with the attempts that Dr. Wright has made to interpret the complex phenomena observed on the planets, will be the first to recognise the great importance of these observations and to hope that the many pressing demands on the instrumental equipment at the Lick Observatory will not prevent further study of the planets by these methods. As Dr. Wright has emphasized, it is more data of observation that are needed, and where can these be better obtained than at the Lick Observatory, under Dr. Wright's expert guidance?

Dr. Wright has written to say that it is a source of great regret to him that circumstances do not permit him to be here to-day to receive the medal in person. A twin-astrographic telescope, with two objectives of 20 inches diameter, one corrected for the photographic and the other for the visual region of the spectrum, is under construction for the Lick Observatory. The mounting embodies a number of innovations in design, for which Dr. Wright is himself responsible, and as its construction has just been commenced, it is essential that he should keep in close touch with the work.

In Dr. Wright's absence, Mr. Hugh Millard, First Secretary of the American Embassy, has kindly attended to receive the medal on behalf of Dr. Wright.

Mr. Millard, in handing this medal to you for conveyance to Dr. Wright, I ask you to assure him that by this award we desire to show our appreciation of a lifetime's work devoted to the advancement of astronomical science and to express to him the high esteem in which he is held by this Society.

ADDRESSES

Delivered by the President on presenting a Jackson-Gwilt Medal and Gift to Mr. F. J. Hargreaves for his Contributions to Astronomy, and to Mr. P. M. Ryves for his Observations of Variable Stars and other astronomical work.

It is now my pleasant duty to present to Mr. Hargreaves the Jackson-Gwilt Medal and Gift, awarded him by the Council for his contributions to astronomy. The grounds for the award are necessarily stated in this very vague way because the work of Mr. Hargreaves has ranged over such a wide field that it is not possible to summarise them in a sentence or two.

Mr. Hargreaves' contributions to astronomical observation have been chiefly in the delineation of planetary detail. He has for many years been an observer of Jupiter and his observations have been incorporated in the reports of the Jupiter Section of the British Astronomical Association, under the Directorship of the Rev. T. E. R. Phillips. Two papers, one in collaboration with Rev. T. E. R. Phillips and Mr. Peek, dealing with the large disturbances in the southern hemisphere of Jupiter in 1928, were published in the *Monthly Notices*.

With an inventive mind and a flair for mechanical design, Mr. Hargreaves has applied his ingenuity in various directions to improve the performance of telescopes and the quality of the observations. He delights in producing a design that can be constructed easily and at small expense in order to do with equal efficiency what has been done by something that is elaborate and expensive. Mention may be made of his screw-and-nut drive for equatorials, which he has applied with excellent results to his own telescope.

Mr. Hargreaves devised an electric drive for telescopes, which he afterwards found was identical in principle with the Gerrish drive. This drive has been very successfully applied to the 28-inch refractor at Greenwich, replacing Airy's water clock. He also designed a modification which, if electric power is not available, enables any type of prime mover to be used. A simple pendulum-sustaining device, for use in conjunction with a telescope drive, forms the subject of another paper. The titles of several of his papers include the adjective *simple*; simplicity is the keynote of many of his ideas and suggestions. It is generally agreed that the simplest way of doing a thing is often the most difficult to think of.

The comparison image micrometer was designed by Mr. Hargreaves as an alternative to the filar micrometer. It was subsequently found that the basic idea was not original and was at least as old as this Society, and that Mr. Hargreaves had even been anticipated in the method he used to form the artificial double star. These ideas had long been forgotten and had not seriously been tried out in practice. He was undoubtedly the first to show conclusively the advantages of this micrometer over the filar micro-

meter for double star observations and the high accuracy of which it is capable. It was Mr. Hargreaves' work that convinced me that a comparison image micrometer should be constructed for the 28-inch refractor at Greenwich, and, though the micrometer has not been long in use, there is no doubt that it has produced a considerable increase in the accuracy of the observations.

Of recent years Mr. Hargreaves has turned his attention increasingly to optical figuring. If, as I have said, he has a *flair* for mechanical design, it is undoubted that he has a *genius* for optical figuring. Genius has been defined as an infinite capacity for taking pains. Though that is no doubt an important element in optical figuring, it is not all. Skill in making and interpreting delicate optical tests is an essential element in work of the highest precision. An accuracy of one-tenth of a wave-length presents no terrors to Mr. Hargreaves. In this room we have often admired the excellence of the solar spectra that Mr. Evershed obtains. The superb quality of these spectra has been made possible by the extremely accurate figuring of the optical parts by Mr. Hargreaves. In work of this sort, making possible more accurate and more delicate observations, Mr. Hargreaves is making an important contribution to astronomy.

Mr. Hargreaves, it is a great pleasure to me to present this Medal and Gift to you on behalf of the Society. We have admired your enthusiasm, your ingenuity and your skill. We all hope that you have many years of useful work before you and we give you our heartiest good wishes for the future.

A Jackson-Gwilt Medal and Gift has also been awarded by the Council to Mr. P. M. Ryves for his observations of variable stars and other astronomical work.

Those who know Mr. Ryves and who have followed his work will acknowledge his intense devotion to astronomy. Ryves—telescope—variable stars is a chain of ideas that is almost inevitably suggested by his name, for it is wellnigh impossible to think of Mr. Ryves apart from his telescope, nor to think of him at the telescope without observing variable stars. His principal work has been the observation of long-period variables. He has been for many years a very assiduous observer, and some twenty papers in the *Monthly Notices* and elsewhere give the results of some of his observations. The characteristic feature of all Mr. Ryves' observations is their very high accuracy.

For some years Mr. Ryves has been resident in Spain, and he has managed to continue his observations under very great difficulties amidst the troubles that have beset that unhappy country. Recently he was compelled to leave Zaragoza, but he managed to take with him the optical parts of the 5-inch equatorial. Within a few days after arriving at Hendaye he had made a temporary mounting for these, mainly of wood, and was able to continue his observations, with little interruption.

In 1931 Mr. Ryves discovered Comet *c* of that year. In the course

of a series of observations of the star U Geminorum, he discovered the comet on August 10 about two degrees from the star. This comet proved notable because of its small perihelion distance.

Mr. Ryves is also an observer of planetary detail, though such work takes second place to the observations of variable stars. His observations have been incorporated in the Memoirs of the Mars and Jupiter sections of the British Astronomical Association. In the year 1922 he went to Teneriffe to observe Mars, at its close approach to the Earth, under more favourable conditions than the southerly declination of the planet permitted in England.

Mr. Greaves, in handing you this medal and the accompanying gift for transmission to Mr. Ryves, I ask you to express to him our admiration of the manner in which he has continued to carry on his observations under most difficult and trying conditions, and our hope that it will not be long before it will be possible for him to continue them in happier circumstances.

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